Northern Region Stake Row Analysis 1998 to 2015

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Errata corrected March 2017

Introduction

The errata corrected in this version is the elimination of stake rows coded as summer plantings, because Regional reforestation experts determined that no planting of summer stock has occurred in the Region during the analysis timeframe. Stands with stake rows coded as summer plantings were reviewed in FACTS and the data was corrected to spring or fall planting, as appropriate.

Stake row survival surveys are installed and measured yearly in Region 1 under the guidance provided in FSH 2409.17, 2.74. These surveys are used to provide consistent data for the annual national plantation survival report of first and third year planted tree survival, and are designed to sample species and stock types over varying site conditions. Each Forest installs a representative sample of staked rows immediately following planting, and reports the survival findings after the first and third growing seasons. This data is consolidated at the Regional level, where it is compiled into an annual seedling survival report. In addition to upward reporting, this used is used in the Region to inform sound management decisions regarding the selection of planting methods, sites, and stock types to achieve reforestation objectives. Reforestation is a crucial piece in adaptively managing the landscape in the context of expected climate conditions, and in meeting the desired conditions outlined in Forest Plans.

The forests of the Northern Region are highly sensitive to projected climate change, and the Region is committed to incorporating adaptation strategies to changing climates into management actions based on the vulnerability of resources to climate change (Scott et al 2013). There are many unknowns about how changing climates will affect disturbance processes, soil moisture deficits, tree growth, mortality, regeneration, and species distribution (USDA 2015). Considerations and management strategies have been articulated in the vegetation chapter of the Northern Rockies Adaptation Partnership (NRAP - Halofsky et al, in press), the Reforestation-Revegetation Climate Change Primer (Scott et al 2013), and in the Northern Region Reforestation Strategy 2016 and Beyond (USDA 2015). Predicted effects of climate change are varied and complex, and may include factors such as increased water deficits and longer growing seasons. The expected responses of vegetation to climate changes and associated feedback loops will also be varied and complex. Changes to microsite conditions will likely govern tree regeneration (Halofsky et al, in press).

The purpose of this analysis is to take a broad look at Regional stake row data in the context of past climate patterns, species, site conditions, and implementation factors that may have influenced tree survival. The intent is to provide information on past trends and patterns to help inform future management decisions. Climate (long term) and weather (short term) change at different spatial and temporal scales (Halofsky et al, in press). While both climate and weather affect site specific seedling survival, this analysis uses yearly averages of climate to analyze seedling survival trends over an 18-year analysis period. A variety of relationships between key climate, site, and implementation attributes are reported along with recommended management considerations. A key hypothesis is that management practices need to be flexible and adaptive; some standard practices of the past may not necessarily yield the desired results in the context of warmer and drier climates.

Methodology

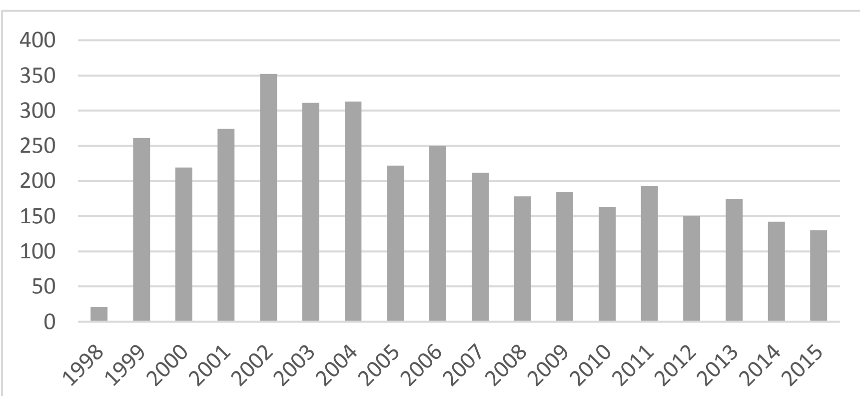
Data Compilation and Summary

The data analysis was conducted using a series of pivot tables in Microsoft Excel to explore trends and patterns of seedling survival based on a variety of attributes. No statistical analysis was done. The data used was compiled from all Regional annual reporting stake row data available from 2000 to 2015, and includes planting years 1998 through 2015. Data prior to 1998 is available, but not in a consistent format. The raw data was modified to eliminate duplicate rows and ensure all coding was consistent. In addition, several data columns were added, including R1 Broad Potential Vegetation Types (PVT), R1 Habitat Type Groups, stock categories, aspect categories, and climate information. PVT and habitat type groups are consistent with the most recent Regional vegetation classification (Milburn et al 2015). See appendix A provides more detail. The initial process yielded a total of 3,778 unique stake rows for the analysis.

Further review by the Regional reforestation specialist resulted in the elimination of several stands due to inconclusive FACTS records, and plantings recorded for the summer season were updated to be spring or fall, as appropriate. A total of 3,749 unique stake rows were ultimately used for the analysis.

The data cover a wide range of localities, species, site factors, and climatic conditions. However, some conditions are represented more than others because they are more common in the areas where reforestation is occurring. Please see appendix B for graphs showing the array of available data. The data results inherently best represent the most common conditions measured. Figure 1 displays the number of stake rows installed each year in Region 1. The number of stake rows installed was highest in the early 2000's, likely in part due to planting that occurred following widespread wildfires in 2000. The forests with the largest planting programs contribute the bulk of the data to the analysis, most especially the Idaho-Panhandle and the Kootenai, and to a lesser extent the Flathead, although all Forests are represented to a degree.

Figure 1: Stake rows surveyed in Region 1 by planting year, 1998-2015



Several of the key attributes described in this paper are represented by the data as follows:

- *Habitat Type*: A wide range of habitat types were recorded. These were grouped into R1 Broad PVT and R1 Habitat Type Groups. The bulk of analysis focuses on R1 Broad PVT. There are ample data points available to represent Warm Dry, Warm Moist, and Cool Moist PVTs but there has been relatively little planting done on Cold broad PVTs. Roughly 50 of the stake rows did not have habitat type recorded; these data were excluded from analyses that examined PVT.

- *Climate*: Climate was represented by 12-month statewide precipitation rankings, temperature rankings, and Palmer Drought Severity Indices (PDSI). While a range of precipitation rankings are represented, all are “moderately wet” or drier. Temperature rankings represented were either normal or higher. The most common PDSI condition was normal or mid-range; however, the sum total of all the drought rankings (moderate, severe, and extreme) is roughly equivalent to the sum total of moist or normal PDSI. The section below describes climate information in more detail.

- *Aspect*: The data cover a wide range of field-recorded aspects. These were categorized into three aspect categories for analysis (dry, moderate, and moist), each well-represented.

- *Tree Species*: The tree species represented include Douglas-fir, Engelmann spruce, lodgepole pine, ponderosa pine, whitebark pine, western larch, western white pine, and western red cedar. Other tree species found in the Region are not typically planted and therefore are not represented. Relatively few whitebark pine or western red cedar stake rows have been measured compared to the other species. The most ample data is available for Douglas-fir, western larch, ponderosa pine, and western white pine. Although lodgepole pine is a major reforestation species, it has low surveyed numbers likely because it is typically managed with natural regeneration. Cottonwood is only represented by one stake row and so is excluded from species analysis.

- *Stock Type*: There is good representation of both basic stock types (bareroot and container). There are some specific stock types with relatively few data available.

- *Season of planting*: Spring is by far the most common planting season used, although data exists for fall planting as well.

- *Field Remarks*: Information on field remarks was summarized based on the identification of keywords. Field remarks are not mandatory when forests submit data. However, this information is useful to display field expertise in context of other trends and attributes when available. Field managers tended to include remarks to explain poor survival or challenges. About 18% of the stake rows had remarks which fit into keywords of interest. The most common remarks were related to climate, site conditions, and animal damage. Operational remarks and problems with pests/pathogens were less commonly noted.

Climate Information

Annual climate trends were derived from data posted by the National Oceanic and Atmospheric Administration (NOAA). The climate data was added to the stake row data based on the year of planting and the location of the stake row (Idaho or Montana). All data was based on statewide annual averages. Three attributes were included to represent the weather and climate patterns from 1998 to 2015:

1. Statewide Temperature Rankings

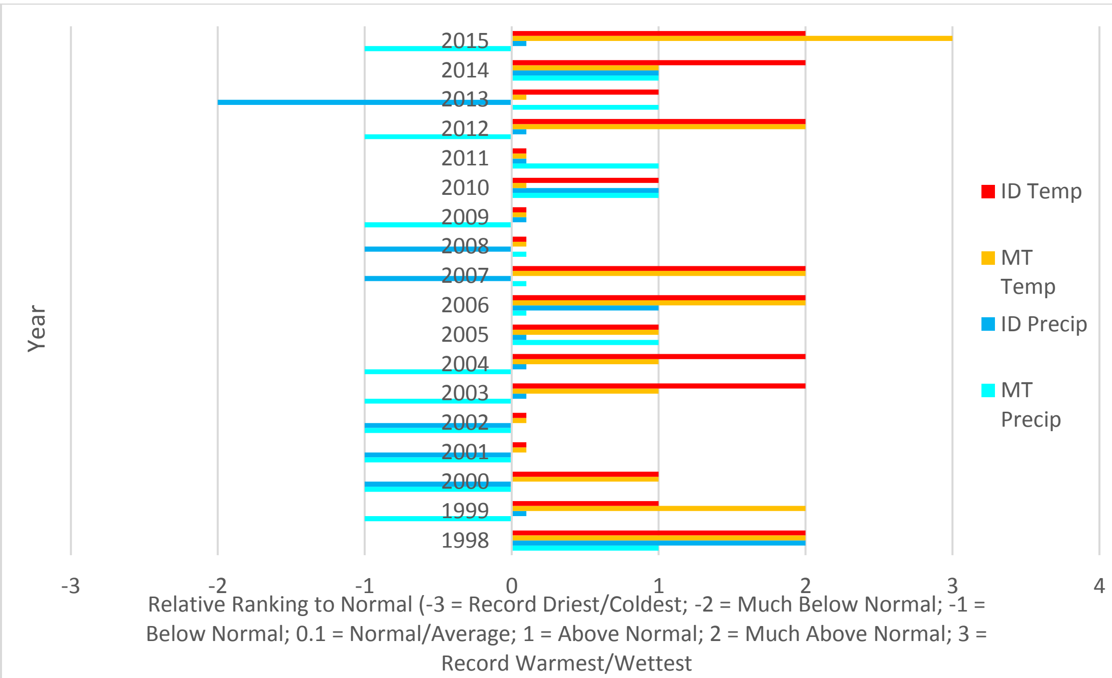
2. Statewide Precipitation Rankings

3. Statewide Palmer Drought Severity Index (PDSI)

The statewide temperature and precipitation rankings are classified into 7 categories relative to the normal (average) condition, based on an average of 12 months (January to December). While monthly and seasonal rankings are available, it was infeasible to break the analysis into that level of detail. Temperature classes range from record coldest, much below normal, below normal, near normal, above normal, much above normal, and record warmest. Precipitation classes range from record driest, much below normal, below normal, near normal, above normal, much above normal, and record wettest.

Figure 2 shows the temperature and precipitation rankings for Montana and Idaho from 1998 to 2015. Average temperature classes in both states have been at (30% of the time) or above (70% of the time) normal for the entire 18-year analysis period. In fact, in 2015 Montana was at its record warmest. Precipitation classes have been variable over the analysis period, often near the normal level or just below, although several years had above average precipitation (1998, 2005, 2006, 2010, 2011, 2013, and 2014). There were also years that experienced a combination of below average precipitation with above average temperature (2000, 2004, 2003, 2007, 2012, 2013, and 2015). Several of these years correspond to lower seedling survival trends.

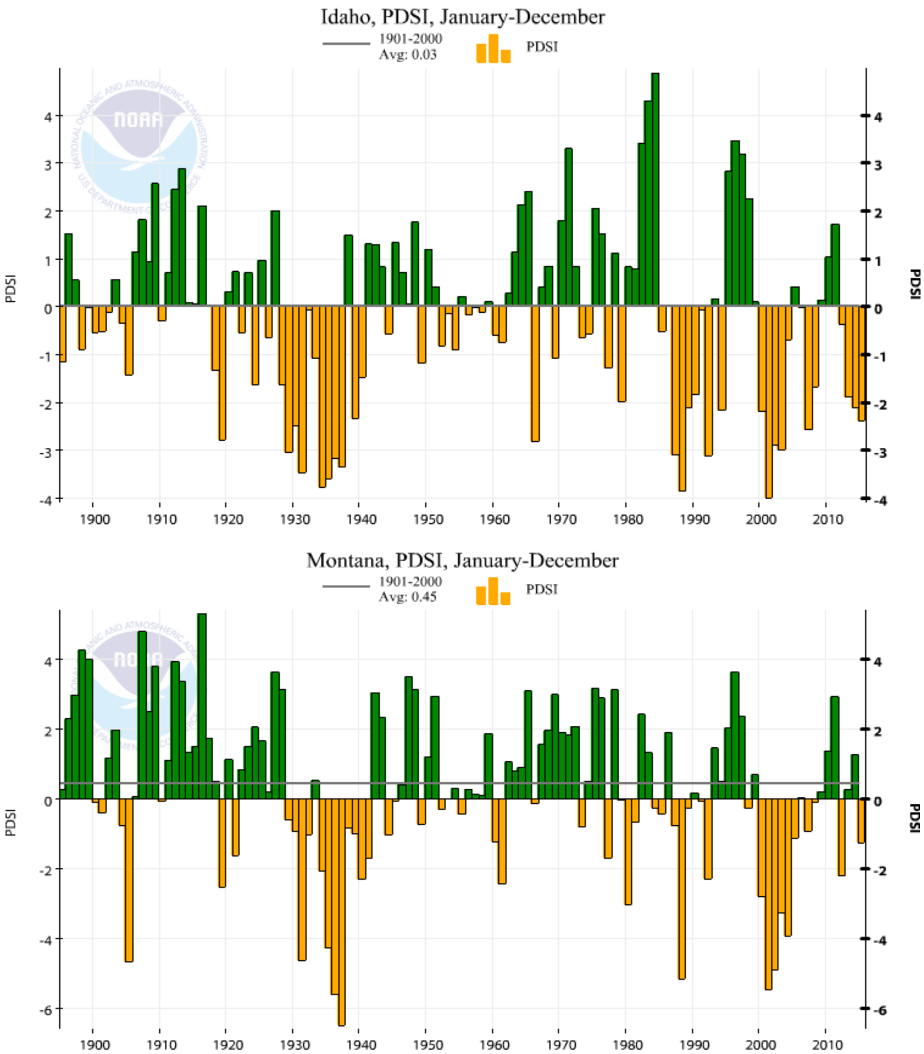
Figure 2: Montana and Idaho Statewide Temperature and Precipitation Rankings (Jan through Dec), 1998-2015; source: NOAA



The Palmer Drought Severity Index (PDSI) is an index of relative dryness based on readily available temperature and precipitation data. This index was classified into 7 classes: extreme drought (-4 and below), severe drought (-3 to -3.99), moderate drought (-2 to -2.99), mid-range (or normal, -1.99 to +1.99), moderately moist (+2 to +2.99), very moist (+3 to +3.99), or extremely moist (+4 and above). A simple split into 2 categories of droughty (-2 and below) versus non-drought (-1.99 and above) was also added to the data to allow for coarse analysis.

Figure 3 displays the trend of Montana and Idaho annual PDSI from 1895 to 2015. The current droughty conditions are somewhat similar to droughts in the 1930's to 1940's. Not surprisingly, recent major fire years in the Region appear to correlate with droughty PDSI periods. Much of our contemporary reforestation expertise may be based on experiences during moist periods, and may need to be adjusted to reflect likely future droughty conditions. Since 2000, Montana and Idaho have primarily been ranked as having moderate to extreme drought conditions. The exceptions were 2006, 2009, 2010, 2011, 2013, and 2014 in Montana, and 2005, 2006, 2009, 2010, and 2011 in Idaho, which were considered low to moderately moist. Other years were considered normal or mid-range. See appendix A for PDSI values.

Figure 3: Idaho and Montana PDSI, January through December, 1895 to 2015



Results and Discussion

This section describes key highlights and findings of the data analysis that managers may find the most pertinent. See appendix B for supplemental data charts of the relationships explored. The results are organized into four categories:

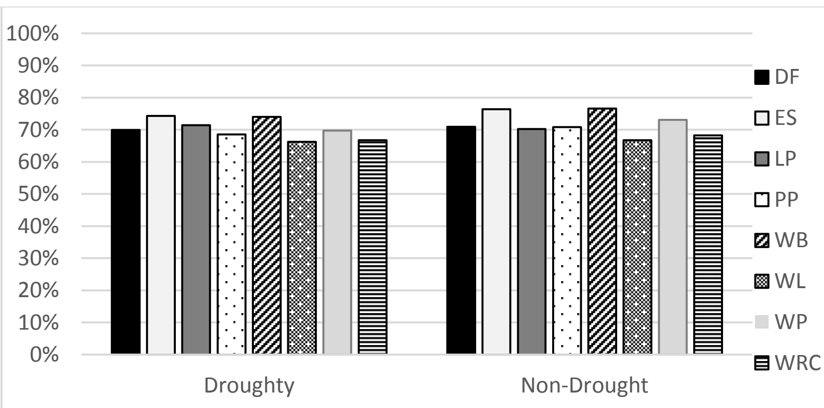
- *Climate*
- *Site Conditions*
- *Implementation Factors*
- *Species-Specific Results*

Climate Influences on Seedling Survival

In this section, data is summarized based on the overall survival of planted trees compared to statewide PDSI, precipitation rankings, and temperature rankings, without additional site attributes. Simple comparisons of Regional average first and third year survival over time to the PDSI of the planting year did not show dramatic trends. Across Region for the 18-year analysis period, average first year survival ranged from 80 to 90% and third year survival from 60 to 80% regardless of the PDSI. Problematic planting years, when the lowest average survivals were recorded across the Region, included 2000, 2003, 2005, 2007, 2009, and 2011; these years correlate to some of the lowest recorded survival by certain tree species as well. These years do not show climate trends that are different from the overall 18-year period; most had droughty PDSI's but several were mid-range or normal. It was infeasible to capture the possible relationships with seedling survival and the PDSI prior to or after the year of planting.

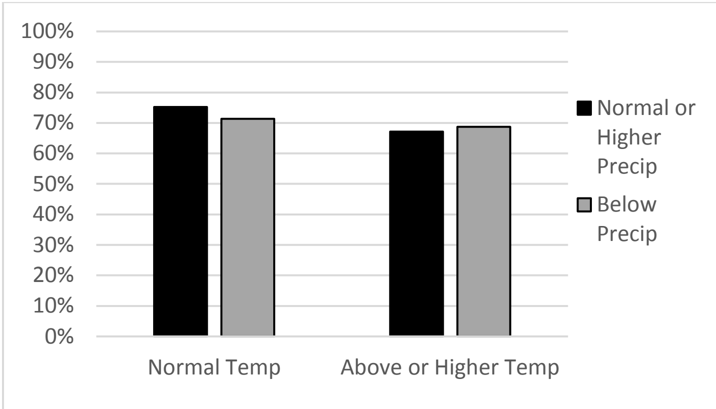
However, as shown in Figure 4, most tree species showed average third-year survival levels that were slightly lower when planted during a droughty PDSI year versus a non-drought year. This trend is particularly evident for Engelmann spruce, whitebark pine, ponderosa pine, and western white pine. Lodgepole pine does not follow this trend, showing slightly higher survival averages during drought years. The results vary in part based on the drought tolerance and strategies of each species, as well as the sites upon which they were planted.

Figure 4: Third year average survival by species and PDSI category



Compared against statewide precipitation rankings, the trend of average third year seedling survival was surprisingly lower during years that were normal or above average in precipitation. There may have been other weather factors that influenced this trend (such as frost). However, when compared to statewide temperature rankings, seedlings showed better third year survival when planted during normal temperature years versus above-normal years. This could suggest that seedling survival may be more sensitive to temperature than precipitation, but we understand that tree growth responds more to water stress than any other seasonal factor on a forest site (Scott et al 2013). Therefore, this trend more likely reflects the fact that years considered below average for precipitation are only slightly below average; whereas the temperature rankings above average tended to be much higher than normal. Figure 5 shows the relationship between survival, temperature, and precipitation.

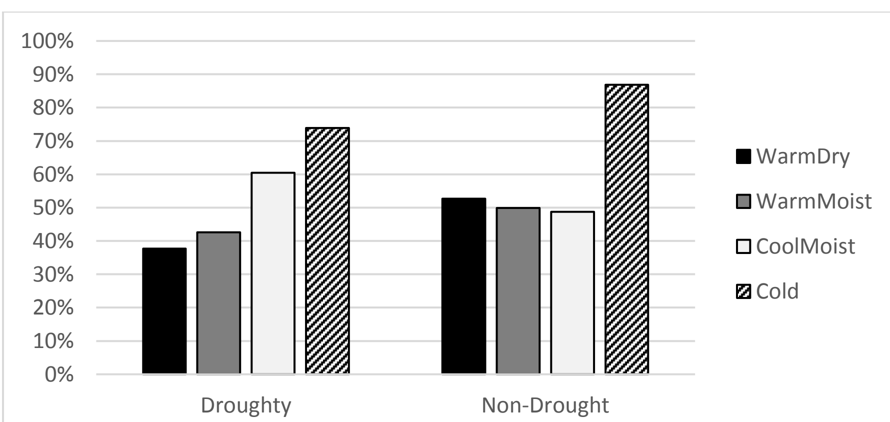
Figure 5: Third year average survival by precipitation and temperature ranking categories



When compared to species-specific survival, precipitation rankings showed similarly variable results. Douglas-fir and western larch appeared to have slightly lower survival during years with above-average precipitation; this is likely explained by the interaction of other factors. Temperature categories showed variation by species as well, although most species showed comparable overall third year survival whether the conditions were normal or above normal. Ponderosa pine, lodgepole pine, and western red cedar in particular appear to survive slightly better when planted during normal temperature years. Conversely, whitebark pine seemed to do slightly better when planted in above-average temperature years, potentially due to the unique limitations found on Cold PVTs where it is typically planted. Refer to appendix B for species survival graphs by precipitation and temperature ranking categories.

Climate concerns were commonly noted in field remarks, most often related to drought or heat stress, although frost or winter kill issues also occurred. Of the stake rows where climate was noted as a causal factor, third year average survival ranged from 30% to 70%, substantially lower than the overall average. The number of instances when climate was cited was greatest in the early and late 2000's. When climate keywords were cited, third year survival was notably lower for bareroot stock, especially Engelmann spruce, western larch, and western white pine. Not surprisingly, the lowest third year survival occurred on sites with dry aspects (see appendix B), and on Warm Dry PVTs when planted during a droughty PDSI year, as shown in Figure 6.

Figure 6: Average 3rd year survival on stake rows with a climate keyword, by R1 Broad PVT and PDSI of planting year



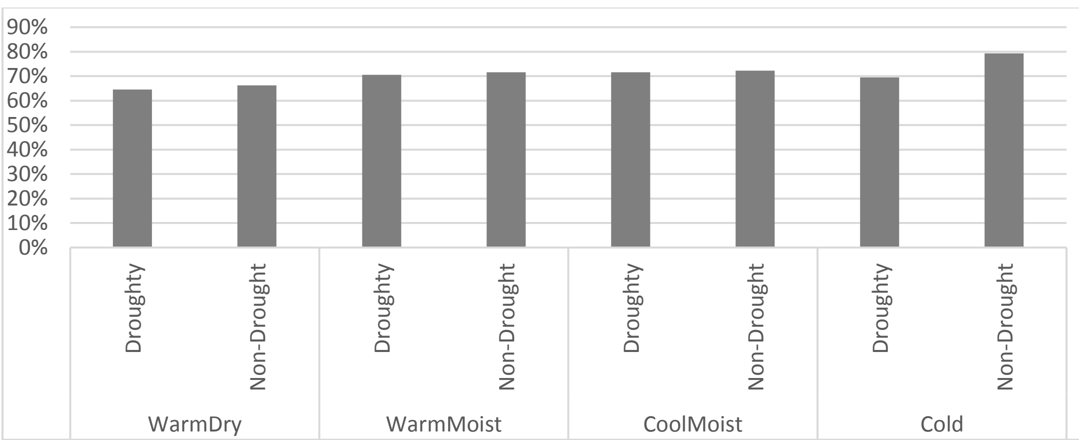
Although climate and weather undoubtedly play a pivotal role in seedling survival, the results indicate that Regional averages over time across site conditions do not fully capture all of the factors that influence seedling survival. The effects of climate are more pronounced and identifiable when combined with other attributes as described in subsequent sections.

Influences of Site Conditions Seedling Survival

It is well known that site selection is of key importance when conducting vegetation management, and especially so when conducting reforestation. Site conditions are considered to be relatively unchanging features that are influenced by factors such as topography and soil type. For this analysis, site conditions are represented by potential vegetation type (PVT), aspect, and related field remarks. In addition, animal damage is discussed in this section, because although it is not necessarily a "fixed" site attribute, it does tend to be inherent to certain locations and related to field conditions rather than implementation factors.

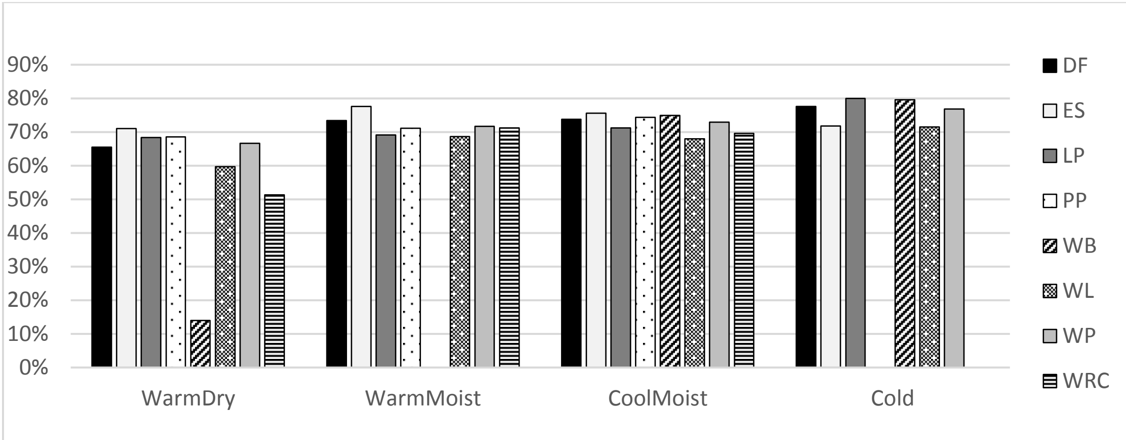
R1 Broad PVTs are groups of habitat types (Milburn et al 2015). On its own, a comparison of broad PVT does not show a compelling influence on survival, although there was a slight trend of lower survival for most tree species on Warm Dry PVTs, trending upward across Warm Moist, Cool Moist, and Cold (see appendix B). As Figure 7 shows, there are only slight trends of lower third year survival for all PVTs during droughty PDSIs compared to normal or moist PDSIs.

Figure 7: Third year average survival by R1 Broad PVT and PDSI category



The third year survival of specific species show general trends with R1 Broad PVT, as shown in Figure 8. Most species have slightly lower survival on Warm Dry PVTs, although ponderosa pine is notably consistent across PVTs. Western larch and western red cedar in particular have shown lower survival on Warm Dry PVTs, as has whitebark pine (although this may be an error in data reporting, as whitebark would not typically be planted on these sites). These trends support the ongoing emphasis of selecting the proper species to plant on the site, supports the common understanding that inherently warm and dry sites are more difficult to reforest, and may become increasingly so in the future.

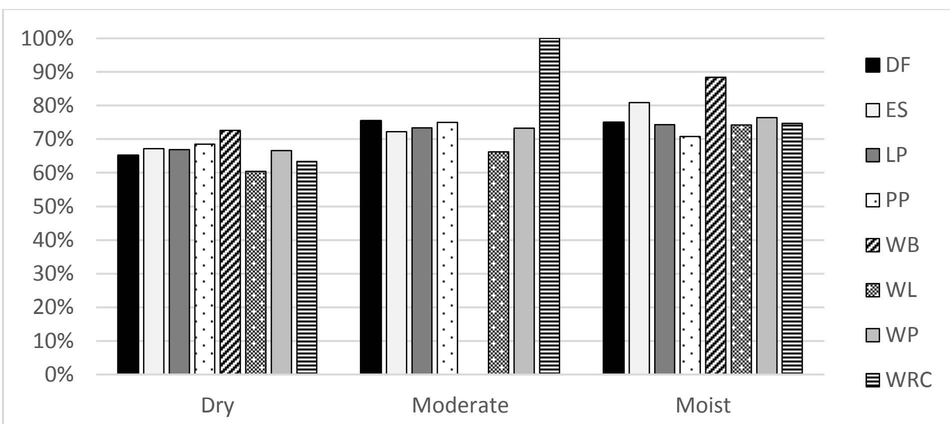
Figure 8: Third year average survival by species planted and R1 Broad PVT



Combining R1 Broad PVT as a site factor with climate shows some general trends which support current assumptions and reforestation practices. More importantly, this attribute provides a backdrop to compare other site conditions and implementation factors.

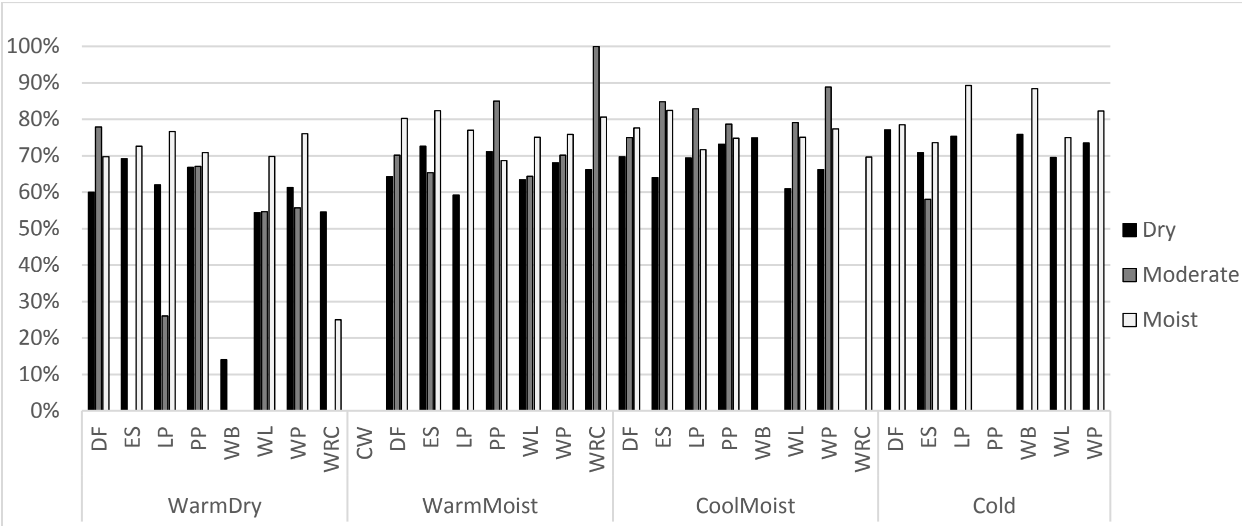
Aspect is one topographical feature that influences the available moisture on a site, and to an extent is inherently represented by habitat types. Aspect combined with PDSI was briefly reviewed but showed no meaningful trend. As shown in Figure 9, however, a comparison of survival by individual tree species and aspect indicated that in general most species had slightly lower average survival on dry aspects versus moderate and moist aspects, a trend which is most pronounced for western red cedar.

Figure 9: Third year average survival by aspect category and tree species



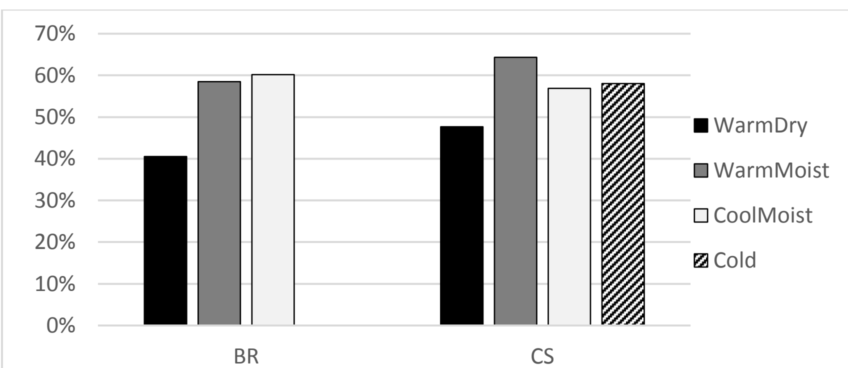
When aspect and broad PVT are compared with average third year survival for individual species, results indicate that survival on dry aspects is lower for most species. This is especially apparent on Warm Dry PVTs, especially for Douglas-fir, lodgepole pine, western larch, and western white pine. The drops in survival based on aspect in these cases could be the difference between certification and failure of a planting unit. Conversely, ponderosa pine survives about the same across PVTs and aspects. In addition, western white pine and western larch show drops in survival on dry aspects in Warm Moist and Cool Moist PVTs. Even on Cool Moist and Cold broad PVTs, the drier aspects tend to support slightly lower survival for most species.

Figure 10: Third year average survival by species, R1 Broad PVT, and aspect category



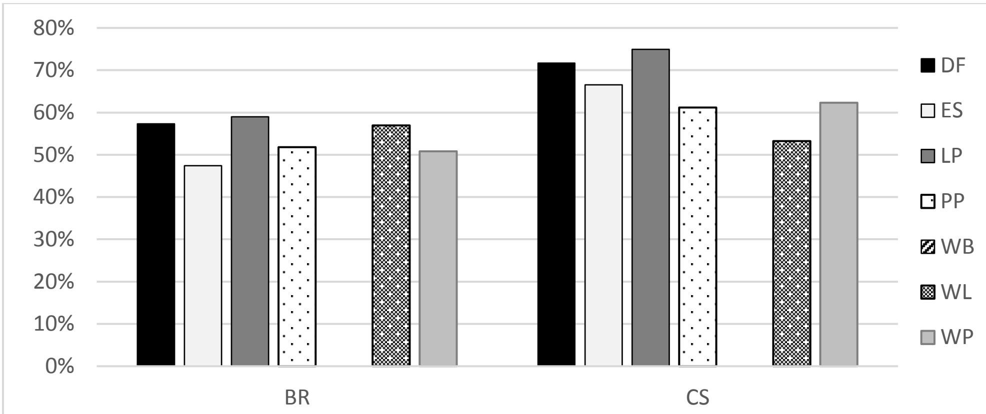
Of the 18% of stake rows with keyword remarks, those related to site were fairly common, including factors such as "harshness", steepness, rockiness, etc. For these stake rows, climate factors were also commonly listed. In stake rows with these remarks, average first year survival ranged from just over 53% to 92%, and third year survival from 38% to 78%, below the overall averages. Of the stake rows that noted site concerns, the lowest third year survival occurred on sites in Warm Dry PVTs, and third year survival tended to be slightly lower with bareroot stock.

Figure 11: Third year average survival in stake rows with a site remark, by R1 Broad PVT and stock type category



Animal damages are not consistently reported in stake rows, but may noted in remarks. Animal damage in particular was a fairly common keyword concern. In stake rows where animal damage was noted as a remark, average third year survival was 50-65%, lower than the overall average. There was not a substantial trend in survival across R1 Broad PVT with animal damage remarks. However, the survival of these stake rows was slightly lower for bareroot stock, especially Engelmann spruce, ponderosa pine, and western white pine as shown in Figure 12.

Figure 12: Third year average survival in stake rows with animal damage remarks, by stock type and species

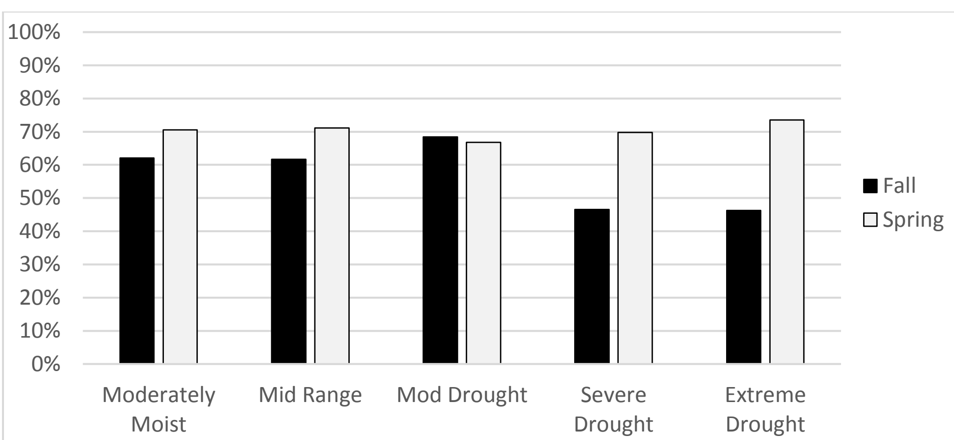


Influences of Implementation Factors on Seedling Survival

Implementation factors include considerations such as season of planting, stock type selection and quality, and operational planting methods and logistics. The data comparison focuses on season of planting and stock type, as these are specified for all stake rows. More generic analysis is made on stock quality and operational planting considerations based on keyword remarks. When combined with climate factors and site conditions, survival trends are more apparent than with any one factor alone.

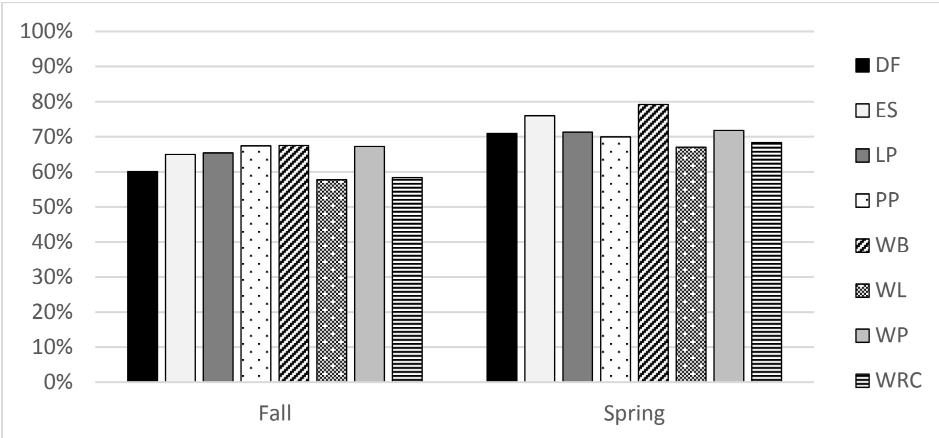
Spring planting occurs far more often than fall planting; summer planting has not occurred in Region 1 during this analysis period. Planting of spring stock can occur into the summer months, particularly on cold, high elevation sites. Many factors influence the decision of when to plant, including site conditions and tree species as well as operational factors such as access or logistical delays. Although it does not occur often, fall planting consistently results in lower 3rd year survival, likely due to the uncertainty surrounding receiving adequate moisture at that time of year. This trend is particularly pronounced during severe and extreme PDSI drought years, as shown in Figure 13. The trend is less compelling when all drought types are combined, and trends across R1 Broad PVT are variable (see appendix B).

Figure 13: Average third year survival by season of planting and PDSI



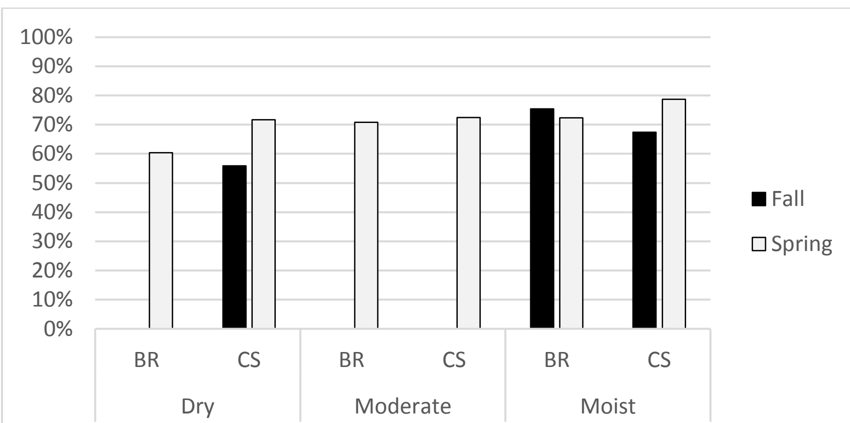
Fall planting generally yields lower third year survival for most tree species, as shown in Figure 14.

Figure 14: Average third year survival by season of planting and species



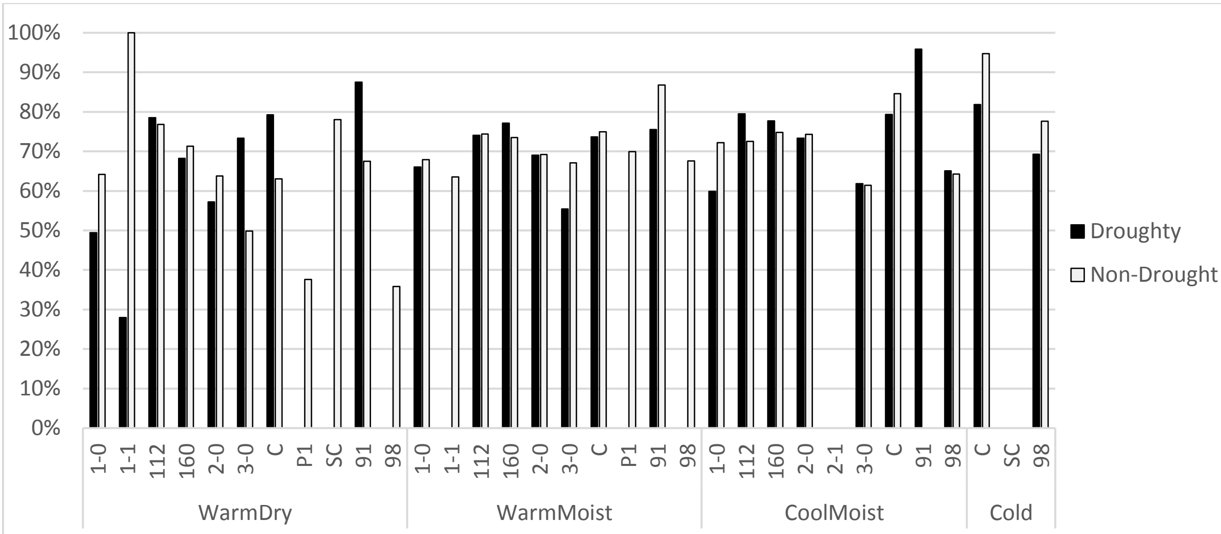
Stock type selection and quality are also important factors for planting success. Specific stock types are recorded for most stake rows. Figure 15 compares third year survival of the main stock type categories (bareroot – BR - versus container stock - CS) to aspect category and season of planting. Container stock typically yields higher survival, at least in the short term, on all aspects and seasons of planting, although the trend is negligible on moderate aspects.

Figure 15: Average third year survival by stock type category, aspect category, and season of planting



Numerous stock types are available from the nursery. Refer to appendix A for descriptions of stock type codes. Figure 16 shows specific stock type performance by R1 Broad PVT and PDSI category. In the Warm Dry PVT, small bareroot stock (1-0 and 1-1) do particularly poorly when planted during a droughty PDSI year. Larger or older stock, whether bareroot or container, appears to do the best especially on Warm Dry PVTs.

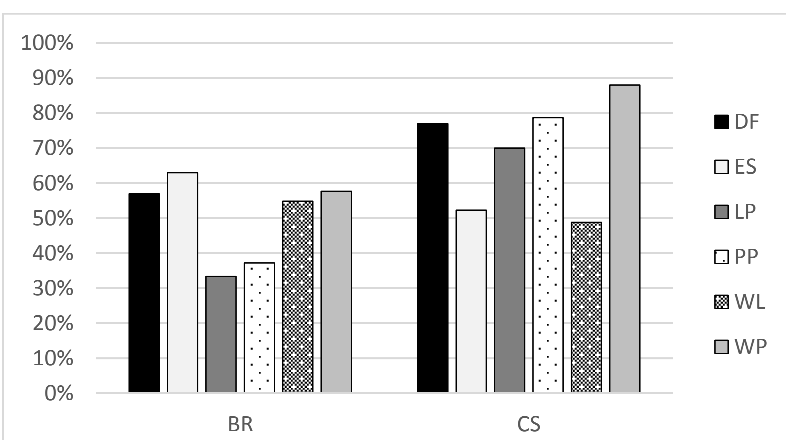
Figure 16: Average third year survival by stock type, R1 Broad PVT, and PDSI category



Genetically improved stock is also available through the Region 1 Tree Improvement Program. 24 stake rows were measured on genetically improved stock during the analysis period, which included Douglas-fir, western larch, ponderosa pine, western white pine, and whitebark pine. In comparing this small sample against the results for the un-improved stock of those species (appendix B), the data indicated that there was slightly better third year survival for improved ponderosa pine and whitebark pine but not for the other species. However, early survival is not the only potential gain expected from improved stock, and important characteristics such as long term survival, growth, and desirable adaptation traits are not expressed in stake rows. Conclusions regarding improved stock should be based on longer term monitoring.

Stock quality from the nursery, including factors such as caliper, root to shoot ratio, and absence of disease influence seedling survival in the field. These attributes are not explicitly noted in stake row data, but were included in some remarks. Relatively few remarks were made regarding stock quality, indicating that continual stock improvements are likely yielding desirable stock quality. Of the small sample with stock concerns noted, average first year survival ranged from 42% to 100% and third year survival from 11% to 91%. The poorest survival occurred where remarks were made relative to bareroot stock, particularly of lodgepole pine and ponderosa pine.

Figure 17: Average third year survival of stake rows with stock remarks, by stock type and species



Operational planting methods and logistics are the last element of implementation influences explored. The process of reforestation planning is complex, with many steps including but not limited to outyear budgeting, ordering trees, growing trees, site preparation, contract development and administration, tree transport, and tree storage. All of these steps may be continual flux based on administrative changes and subject to weather and other factors in the field. Operational considerations are not recorded in stake rows, but concerns or problems were sometimes noted in the keyword remarks. These included remarks related to tree handling, planting quality, and logistical challenges. Of the relatively few stake rows with these remarks, average first year survival ranged from 56% to 97%, and third year from 21% to 77%.

Species-Specific Results

Douglas-fir (Pseudotsuga menziesii)

From 1998 to 2015, Regional average first year survival of planted Douglas-fir ranged from 65% to 98%, and third year survival from 57% to 87%. The planting years that resulted in the lowest third year survival were 1998, 2006, 2009, 2011, and 2012, which were primarily drought years. Survival when planted in the fall is lower, especially when using bareroot stock. Survival on Warm Dry PVTs is slightly lower regardless of PDSI of planting year. Bareroot and container stock perform similarly for spring planting, while container stock does a bit better fall planting.

Figure 18: Douglas-fir average third year survival by stock type, R1 Broad PVT, and season of planting

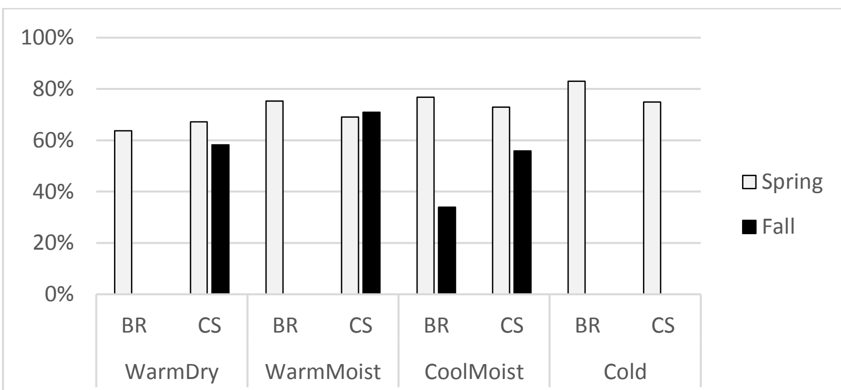
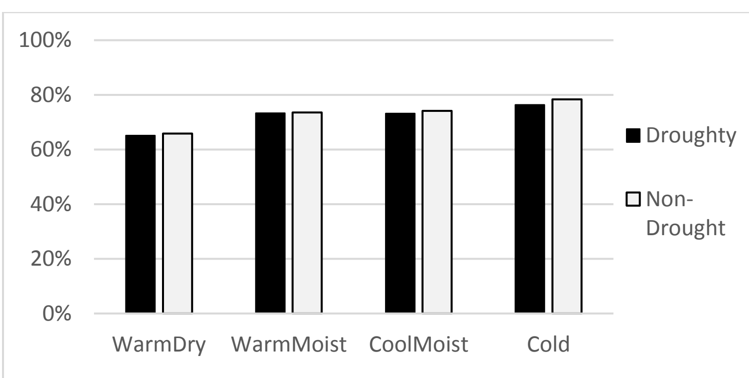


Figure 19: Douglas-fir average third year survival by R1 Broad PVT and PDSI category



Engelmann spruce (Picea engelmannii)

From 1998 to 2015, Regional first year survival of planted Engelmann spruce ranged from 77% to 100%, and third year survival from 58% to 93%. The planting years of lowest survival were 2000 and 2007, both notable drought years. Survival trends overall are relatively consistent across stock types and PVTs, with fall planting showing generally lower results than spring planting except on Cold PVTs.

Figure 20: Engelmann spruce average third year survival by stock type, R1 Broad PVT, and season of planting

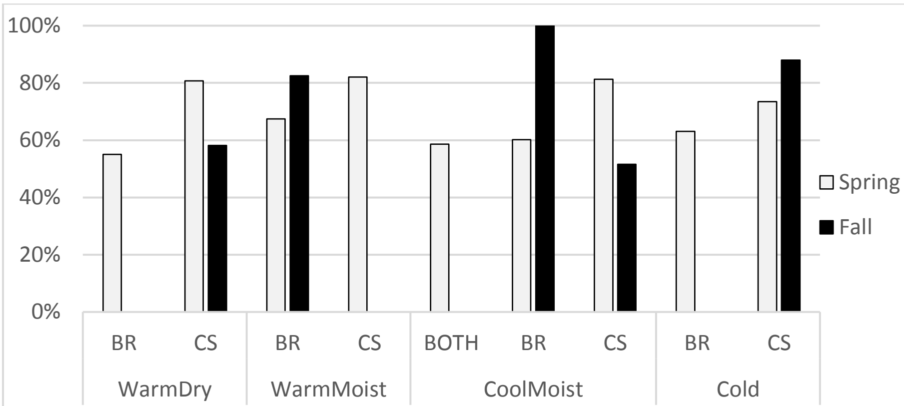
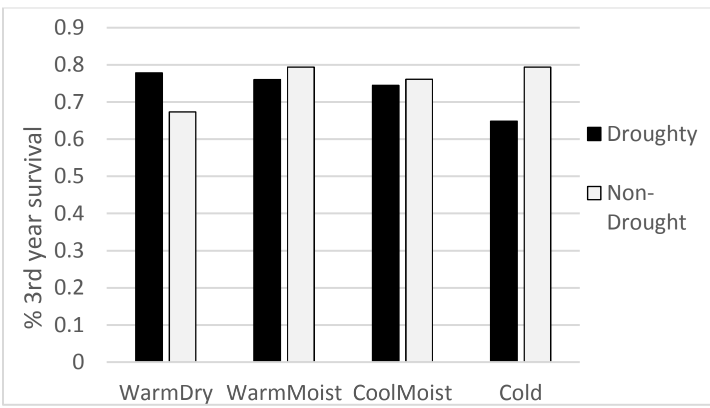


Figure 21: Engelmann Spruce average third year survival by R1 Broad PVT and PDSI category



Lodgepole pine (Pinus contorta)

The gap between first and third year average survival for lodgepole pine across the Region is relatively small compared to other species, indicating that when mortality occurs it tends to be in the first growing season. First year average survival from 1998 to 2015 ranged from 68% to 98%, and average third year survival from 57% to 89%. The planting years with lowest survival were 2000, 2003, 2006, 2007, and 2009, all drought years. Container stock generally performs better than bareroot stock. Fall planting generally yields slightly lower survival except in Warm Moist PVTs.

Figure 22: Lodgepole pine average third year survival by stock type, R1 Broad PVT, and season of planting

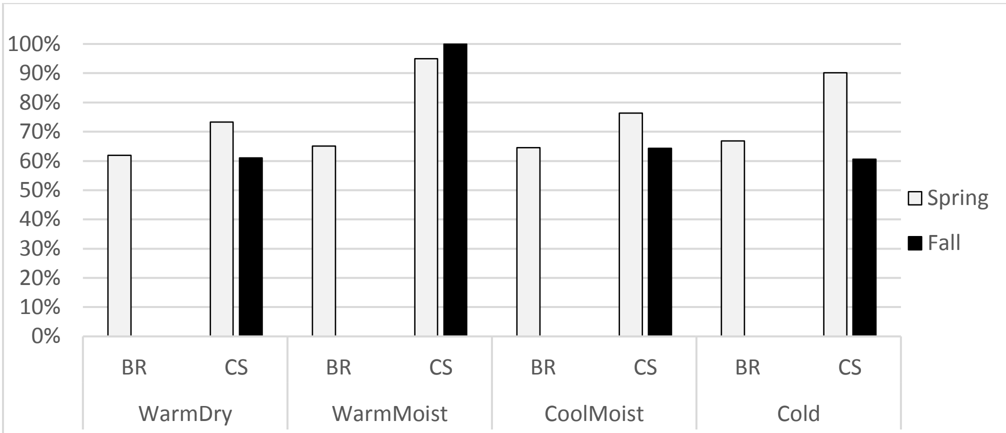
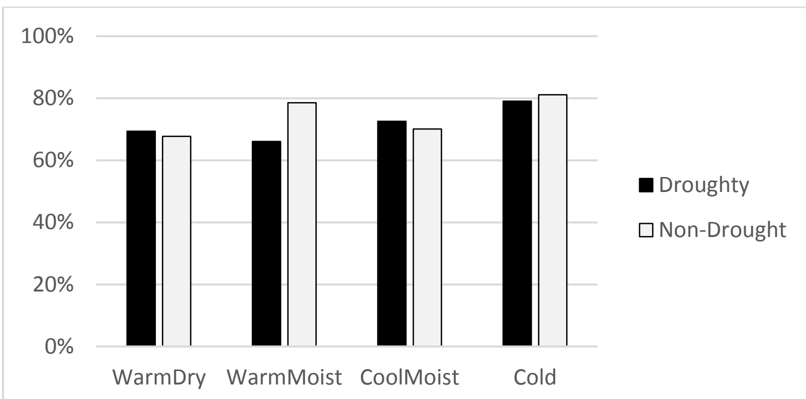


Figure 23: Lodgepole pine average third year survival by R1 Broad PVT and PDSI category



Ponderosa pine (Pinus ponderosa)

First year average survival from 1998 to 2015 ranged from 63% to 96%, and average third year survival ranged from 49% to 89%. The planting years with lowest survival were 1999, 2000, and 2011. Spring planting is the most successful season. Container stock tends to do better than bareroot for early survival. Survival during droughty PDSI's is particularly low on Warm Dry and Warm Moist PVTs compared to non-drought years; this may in part be due to the fact that this species tends to be planted on the driest sites.

Figure 24: Ponderosa pine average third year survival by stock type, R1 Broad PVT, and season of planting

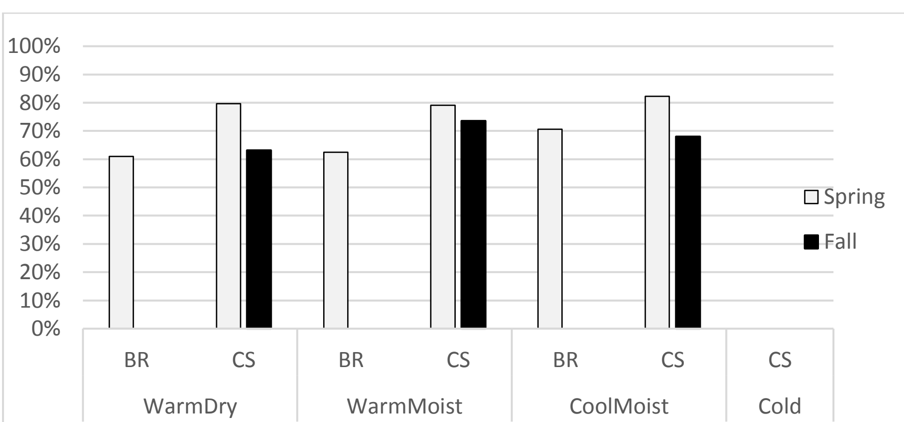
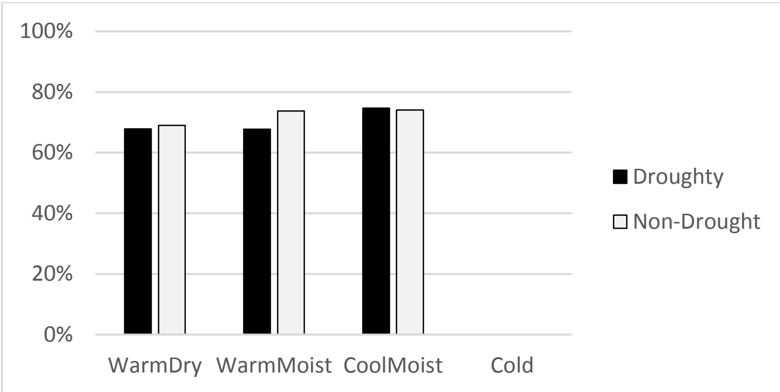


Figure 25: Ponderosa pine average third year survival by R1 Broad PVT and PDSI category



Whitebark pine (Pinus albicaulis)

Whitebark pine was not planted every year, and therefore less data is available than for most other species. From 1998 to 2015, average first year survival ranged from about 79% to 98%, and average third year survival ranged from 41% to 92%. The planting years with the lowest survival were 2002 and 2011. Only container stock is developed for whitebark pine. Spring planting of whitebark often occurs in the summer months due to cold, high elevation site conditions. Fall can be a viable season for planting, but there have been some low survival occurrences. It is unclear if the planting of whitebark on a Warm Dry PVT is possibly an error in reporting.

Figure 26: Whitebark pine average third year survival by stock type, R1 Broad PVT, and season of planting

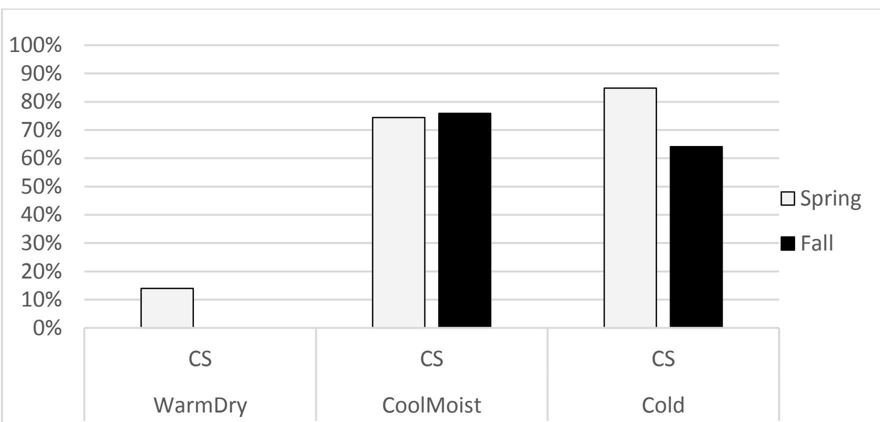
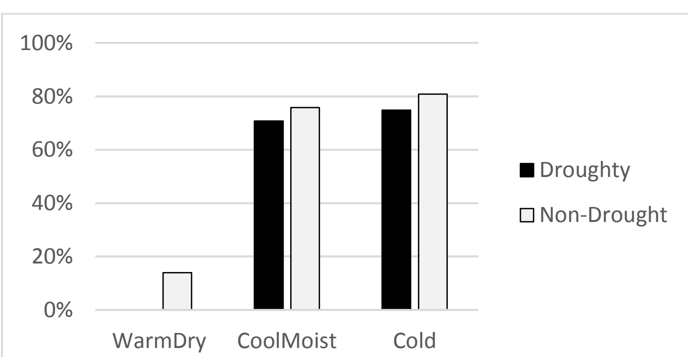


Figure 27: Whitebark pine average third year survival by R1 Broad PVT and PDSI category



Western larch (Larix occidentalis)

From 1998 to 2015, average first year survival in Region 1 has ranged from about 70% to 94%, and third year survival has ranged from 52% to 76%; these ranges are overall slightly lower than the other species planted in the Region. The planting years with the lowest survival were 1998, 2003, and 2007. Some low survival levels have been reported on Warm Dry PVTs with bareroot stock, and Cool Moist PVTs with container stock. This species appears to be particularly sensitive to site selection.

Figure 28: Western larch average third year survival by stock type, R1 Broad PVT, and season of planting

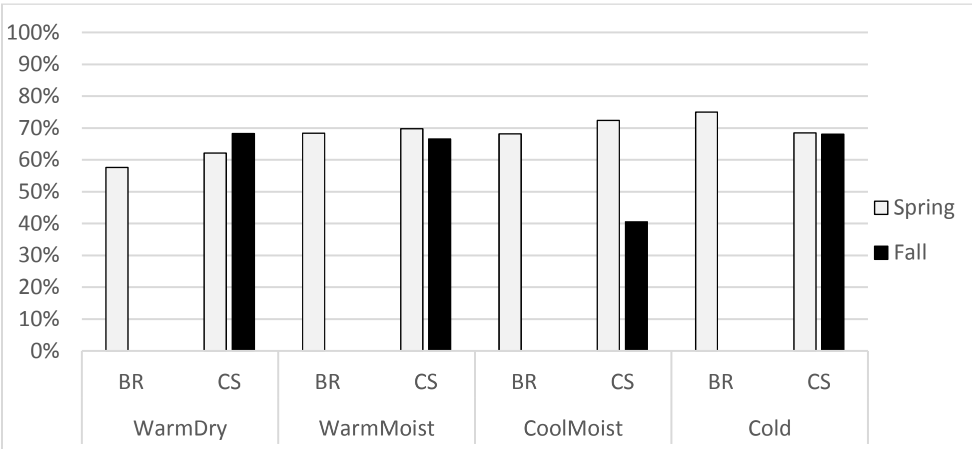
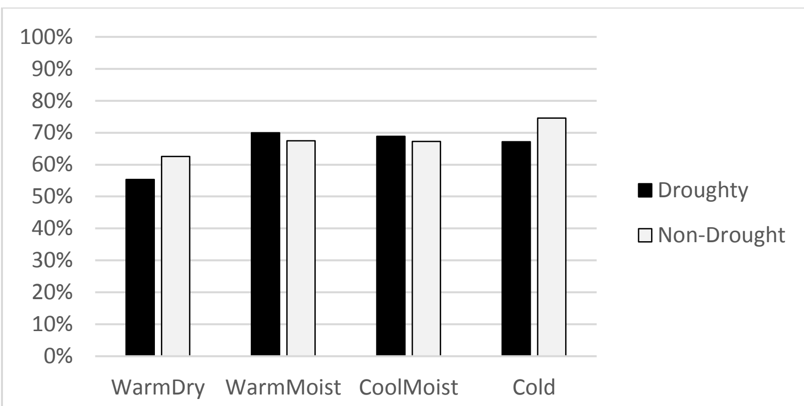


Figure 29: Western larch average third year survival by R1 Broad PVT and PDSI category



Western white pine (Pinus monticola)

From 1998 to 2015, Regional average first year survival ranged from 77% to 97%, and third year average survival ranged from 61% to 87%. The ranges of survival have been particularly even through time for this species. The planting years with the lowest survival were 2000, 2005, and 2011. Fall plantings have been relatively successful. Planting on Cold PVTs appears to be the most sensitive to the effects of the PDSI of the planting year.

Figure 30: Western white pine average third year survival by stock type, R1 Broad PVT, and season of planting

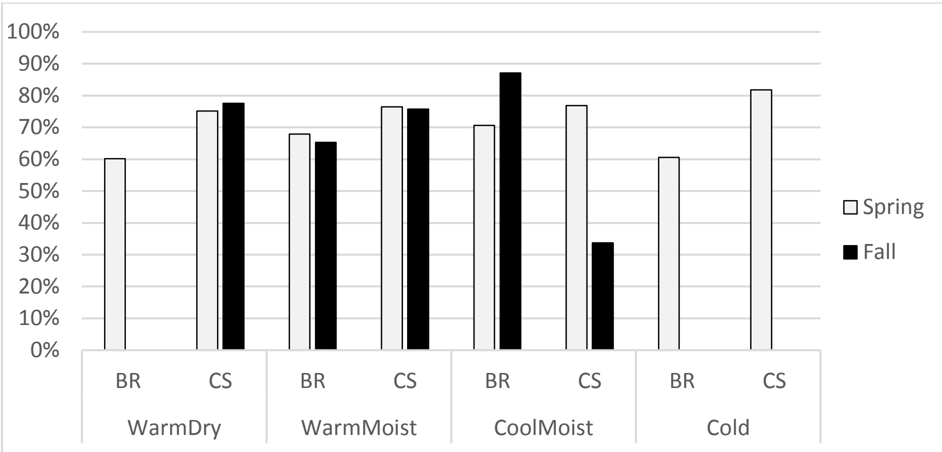
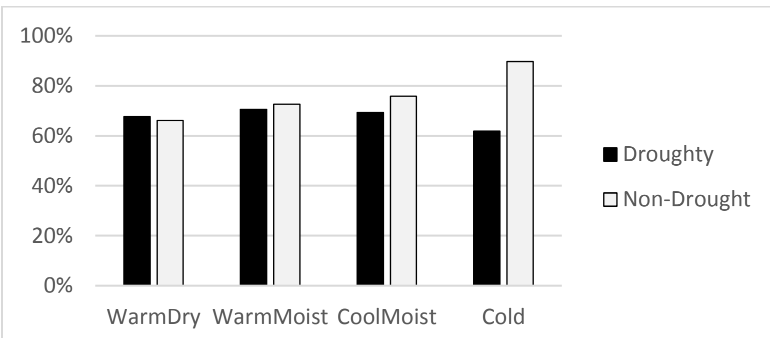


Figure 31: Western white pine average third year survival by R1 Broad PVT and PDSI category



Western red cedar (Thuja plicata)

From 1998 to 2015, Regional average first year survival ranged from 57% to 100%, and third year average survival ranged from 39% to 89%. The planting years with the lowest survival were 1999, 2005, and 2008. Survival of western red cedar has generally been low on Warm Dry PVTs in general, especially if fall planted. Generally container stock does slightly better than bareroot. This species would be particularly sensitive to selecting only the wettest sites for planting.

Figure 32: Western red cedar average third year survival by stock type, R1 Broad PVT, and season of planting

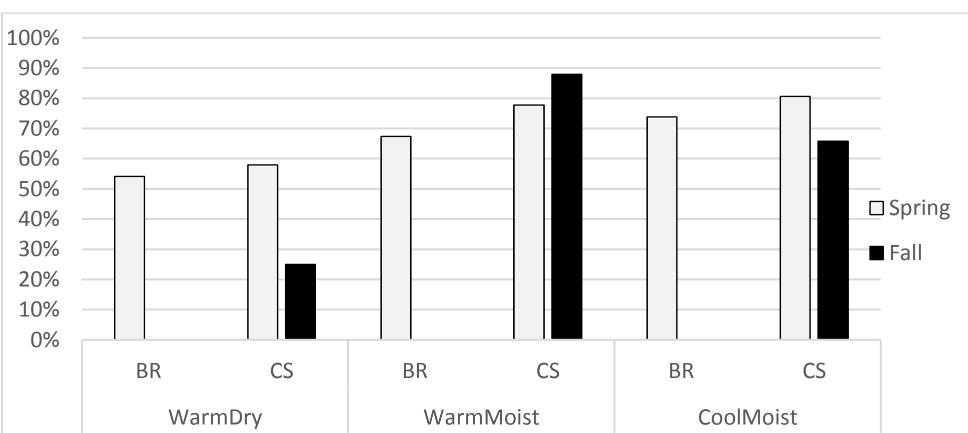
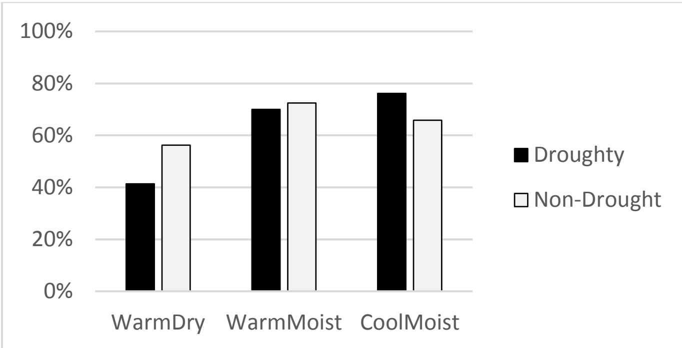


Figure 33: Western red cedar average third year survival by R1 Broad PVT and PDSI category



Management Considerations

Water availability is expected to be a major limiting factor amplifying the already relatively dry conditions common to Region 1 (Scott et al 2013); therefore trends in seedling survival seen during droughty PDSI's may become increasingly pronounced in the coming years. Based on the analysis of stake row survival data from 1998 to 2015, especially the performance of planted stock during drought years, the following considerations for management apply. These considerations complement guidance found in the Northern Region Reforestation Strategy, the Reforestation-Revegetation Climate Change Primer for the Northern Region, and the Northern Rockies Adaptation Partnership. The species discussed are those which had available stake row data, although additional species occur in the Region (such as cottonwood, aspen, grand fir, limber pine, subalpine fir, western hemlock, alpine larch, and green ash) and could be important components of reforestation programs.

- Operational remarks (such as issues with stock, tree handling, and planting logistics or quality) were less commonly noted than other issues and may reflect the continuing Regional improvements and monitoring of stock development and planting procedures. Continuing these efforts is important to ensuring survival in the context of warm and dry climate conditions.

- Fall planting should be evaluated carefully and only employed on the most appropriate sites and species. The data show that spring is by far the most common season of planting, which is likely a result of recent experiences that have shown the difficulty in achieving the necessary moisture during the other seasons, especially in drought conditions.

- Site selection, including a consideration for R1 Broad PVT, is crucial to achieving seedling survival success. A careful assessment of the productivity and suitability of Warm Dry PVT sites moving into the future, particularly on the driest habitat types in that group, is important from the Forest Planning scale down to the development of site specific prescriptions. In addition, planting success may be increasingly driven by microsite conditions; therefore, in all areas carefully consider the influences of site conditions such as aspect, steepness, soil type, and the like to develop site-specific prescriptions.

- Consider the methods needed to achieve reforestation success, especially on dry aspects in Warm Dry PVTs, such as shading techniques and the conservation of soil moisture. Expect that future survival rates may only be achievable at the lower end of historic ranges (correlated with drought years), and consider that planting numbers may need to be adjusted to account for mortality.

- Carefully assign the right stock type and species for the site, including the use of improved stock when appropriate. Use the latest seed zones provided by Region and guidance for assisted migration, and maintain high genetic diversity in seed lots. Generally emphasize the use of early seral species, considering that low density may be appropriate. Consider the benefits and tradeoffs of each stock type relative to site conditions and tree species; for example, bareroot stock overall tends to yield lower early survival but may still be the most inexpensive choice to yield acceptable long-term survival on some sites. Assess the potential for animal damage, especially on bareroot stock. Note that the Coeur d'Alene nursery provides detailed descriptions of the appropriate application and constraints of each stock type that they provide.

- *Douglas-fir* is highly adapted to a wide range of moisture regimes, but is limited by growing season frosts at high elevations (Scott et al 2013). Douglas-fir tolerates drought better than nearly all of its competitors except for ponderosa pine (Halofsky et al, in press). Carefully assess planting of Douglas-fir on dry aspects on the drier end of the Warm Dry PVT (possibly favoring ponderosa pine instead), but also note that this species may be favored over lodgepole pine near its upper limits due to its drought tolerance.

- *Engelmann spruce* is best suited for high elevation, cool and moist settings (Scott et al 2013), but survival data also shows it can be successful in Warm Dry or Warm Moist settings on the appropriate site (likely in or near riparian areas). This species does not tolerate drought well, although it is highly frost-tolerant and can tolerate seasonal standing water (Halofsky et al, in press). The species is likely to retract from previously suitable sites that become too dry; therefore careful selection of moist conditions is important if this species is to be planted.

- *Lodgepole pine* is best adapted to mid- to high-elevation sites due to its high frost resistance in the winter and during growing season frosts; it may retract from dry sites (Scott et al 2013), and possibly expand into colder sites. Lodgepole is intermediate in its needs for water, requiring more than Douglas-fir but less than spruce or subalpine fir; it is highly tolerant of frost and drought, although both are common causes of mortality in first-year seedlings (Halofsky et al, in press). This species is not planted often due to high success with natural regeneration. Use caution if considering planting in the Warm Dry PVT, consider favoring Douglas-fir instead on drier sites, and consider selecting lodgepole over spruce and fir on cooler/moister sites.

- *Ponderosa pine* is the most heat and drought resistant conifer in the Region, and may expand its range into areas currently dominated by Douglas fir, although the driest sites may inhibit establishment (Scott et al 2013). Some of the low survival trends seen with ponderosa pine may reflect that it is chosen for planting on some of the toughest sites. Consider that some of the driest sites may no longer be suitable for this (or any conifer) species, or that stocking at a very low density may be appropriate. Consider also selecting ponderosa pine over Douglas-fir, possibly at higher elevations where frost damage would have limited it in the past.

- *Whitebark pine* is specially adapted to cold, dry, high elevation sites that limit other species, and regeneration could be enhanced by longer and warmer growing seasons; however, it also faces risks due to blister rust and other factors (Scott et al 2013). Whitebark can tolerate long periods of drought, and is generally only limited by competition, and the influences of climate change are highly uncertain. The data support that unlike most other species, survival may be higher during warm periods for planted whitebark, and fall planting may be appropriate especially on the Cold PVT.

- *Western larch* is found in Warm Moist and Cool Moist PVTs in parts of the Region, and given its low water-use efficiency will likely be limited to low energy aspects as higher energy aspects get too hot and dry (Scott et al 2013; Halofsky et al, in press). The stake row data show that western larch is one of the most challenging species for achieving high seedling survival. It is limited by low temperatures at upper elevations and lack of moisture at lower extremes, and while it can survive seasonal drought it performs poorly when droughts last more than one or two years (Halofsky et al, in press). Use caution if considering planting in the Warm Dry PVT, especially on dry aspects. Consider that it might do well on cooler sites where cold temperatures would have limited it in the past.

- *Western white pine* grows in elevation gradients in warm and moist forests in parts of the Region, and will be favored on more mesic sites with good water holding capacity; it may recede from some dry habitat types but could be the most adapted species on mesic sites (Scott et al 2013). Seedlings have low drought tolerance, and mortality late in the first season can occur due to high surface temperatures and/or drought in in areas where root penetration is low (Halofsky et al, in press). Long term success will be influenced by the response of white pine blister rust to warm and dry climates; therefore use of improved stock is particularly important for this species. Use caution if considering planting in the Warm Dry PVT, especially on dry aspects.

- *Western red cedar* occurs in parts of the Region and prefers areas with a consistent mesic condition, and may decline in favor of seral species (Scott et al 2013). It is very shade tolerant, and has little tolerance for drought but can exist in seasonally wet areas especially near riparian systems (Halofsky et al, in press). The stake row data show that this species may be problematic for achieving high survival, although that is based on relatively little data. Site selection, focused on the wettest sites, will likely be important for planting success of this species.

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Appendix A: Data Compilation Methodology

Consistently derived and formatted data was available in Regional Office electronic files from 2000 to 2015. Information from earlier years (98, 99) is also found in the data calls for 2000 and 2001. 2000 is represented only by the information available in the 2002 data call; the reports from 2000 had similar data but without all the attributes used from 2001 on. A summary spreadsheet reporting gross summaries back to 1986 was also available, but detailed attributes were not available. The following steps were taken to establish consistency and add information for analysis.

- Copied and pasted all Regional combined data for each year from electronic stake row folders. Pasted by year pairs, sorted by stand ID, and eliminated duplicates (i.e., where the 3rd year posting including the 1st year results, eliminated the 1st year line so the 1st year data wasn't counted twice). As needed stand ID formats were made consistent. At the end of this sorting and elimination of duplicate data, there were 3,778 rows of data.
    - There are more 1st year than 3rd year results, because in some cases the Forests did not conduct the 3rd year measurement. This can be due to wildfires or replanting as well as operational difficulties; or, in the case of 2014 and 2015, the third year measurement has not yet occurred. A few (4) rows of data recorded 0 trees staked – these were eliminated.
- Made column headings and data labels consistent by filtering each field and fixing typos, inconsistent coding, etc.
- Added Aspect Category column, which groups recorded aspects.
    - Moist = NE, NW, E, ENE, ESE, Evar, N, N/NW, N/NE, N/NW, NE, N-E, NE/N, NEvar, NNE, N-NE, NNW, Nvar, NW, NW NE.
    - Dry = S, SW, S/SE, S/SW, S/W, SE, SE var, S-SE, S-SW, SW, SW/W, SWW, W, W, NW, W/S, W/NW, W/SW, W-NW, WSW, W-SW
    - Moderate = E-S, ESW, E-W, flat, LE, LR, LR/S, LR-N, Lvl, N/S, NE/SE, NE/S, Rolling, SE-E, SW/NE, V, W/E, W/N, W-NE
- Added a Stock Category column to lump all BR and CS types. Some stands had both. Stock Types were edited to use consistent codes. When multiple stock types were listed, the stock category lists Both but the stock type edited to reflect just the first type listed. Added column for Improved Stock, incorporating the improved stock notations from the Remarks column.
- Added Remarks Keywords column. Detailed remarks and those not pertinent (i.e., logistic or record-keeping remarks) were ignored. Many rows did not have useful remarks. Some comments were lost in deleting duplicate stands, but an attempt was made to capture pertinent keywords.
    - Operational = logistical challenges, tree handling, planting quality, human damages, etc
    - Stock = notes about quality of tree stock (roots, caliper, thawing at nursery, etc
    - Climate = weather, drought, winter kill, frost, moisture stress, heat stress, etc
    - Site (Selection & Preparation) = site quality, harsh, rocky, steep, site prep, competition, microsites, soils, etc
    - Animal Dmg = elk, gophers, browse, trampling, livestock, rabbits, etc
    - Pests/Pathogens = western spruce budworm, etc.

- A R1 broad PVT and R1 Habitat Type Groups columns were added and crosswalked from the Hab Type column. About 50 records were blank for habitat type; these are kept in for the analysis, but were eliminated from specific pivot tables done with broad PVT or habitat type groups.

Climate information was added to 6 columns: Precip (MT or ID as appropriate statewide ranking for annual average precip), Precip Category (below or normal/above normal); Temp (MT or ID as appropriate statewide ranking for annual average temp), Temp Category (normal or above and higher), PDSI (annual average Palmer Drought Severity Index for MT and ID as appropriate), and PDSI category (lumped into whether PDSI indicated a drought or normal/moist).

- Climate trends were added based on the year of planting
- Climate data available from NOAA was used to characterize temperature, precipitation, and Palmer Drought Severity Index: http://www.ncdc.noaa.gov/sotc/national/201513. The *National Overview report* for each year describes trends including state-wide precipitation and temperature. Data is also available by season but was not incorporated for the initial analysis.
- Temperature is classified from warm to cool (1 being coldest and 105 being warmest), relative to the normal or average: record coldest, much below normal, below normal, near normal, above normal, much above normal, or record warmest.
- Precipitation is classified from dry to wet (1 being driest and 105 being wettest), relative to the normal or average: record driest, much below normal, below normal, near normal, above normal, much above normal, or record wettest. The data used for both attributes was the January through December Statewide ranks.

Table 1: January-December Statewide Rankings for Precipitation and Temperature in Idaho and Montana, 1998-2015, NOAA

Year	Precip – MT	Precip - ID	Temp – MT	Temp - ID
1998[1]	Above (87)	Much Above (111)	Much Above (112)	Much Above (111)
1999[1]	Below (39)	Near Normal (48)	Much Above (116)	Above (94)
2000	Below (17)	Below (31)	Above (82)	Above (93)
2001	Below (11)	Below (14)	Near Normal (69)	Near Normal (44)
2002	Below (32)	Below (12)	Near Normal (60)	Near Normal (69)
2003	Below (29)	Near Normal (41)	Above (98)	Much Above (108)
2004	Below (29)	Near Normal (61)	Above (94)	Much Above (100)
2005	Above (81)	Near Normal (74)	Above (100)	Above (87)
2006	Near Normal (44)	Above (89)	Much Above (111)	Much Above (102)
2007	Near Normal (59)	Below (14)	Much Above (105)	Much Above (109)
2008	Near Normal (58)	Below (23)	Near Normal (51)	Near Normal (47)
2009	Below (33)	Near Normal (52)	Near Normal (46)	Near Normal (67)
2010	Above (104)	Above (78)	Near Normal (67)	Above (90)
2011	Above (101)	Near Normal (44)	Near Normal (63)	Near Normal (43)
2012	Below (23)	Near Normal (77)	Much Above (116)	Much Above (116)
2013	Above (102)	Much Below (12)	Near Normal (77)	Above (89)
2014	Above (106)	Above (92)	Above (82)	Much Above (117)
2015	Below (29)	Near Normal (49)	Record Warmest (121)	Much Above (120)

[1] Statewide ranking maps not available for these years; information found on web pages noted in citations.

- The Palmer Drought Index is classified into ranges by NOAA: extreme drought (-4 and below), severe drought (-3 to -3.99), moderate drought (-2 to -2.99), mid-range (-1.99 to +1.99), moderately moist (+2 to +2.99), very moist (+3 to +3.99), or extremely moist (+4 and above).
    - PDSI was also translated into “PDSI category”, which simply split droughty (below midrange) and non-droughty (mid-range and above), for more lumped analysis.

Table 2: Palmer Drought Severity Indices for Idaho and Montana, 1998-2015, NOAA

Montana			Idaho		
Date	**Value**	**Category**	**Date**	**Value**	**Category**
1998	-0.27	Mid-Range	1998	2.26	Moderately Moist
1999	0.70	Mid-Range	1999	0.10	Mid-Range
2000	-2.79	Moderate Drought	2000	-2.18	Moderate Drought
2001	-5.48	Extreme Drought	2001	-3.99	Severe Drought
2002	-4.92	Extreme Drought	2002	-2.9	Moderate Drought
2003	-3.27	Severe Drought	2003	-2.99	Moderate Drought
2004	-3.93	Severe Drought	2004	-0.69	Mid-Range
2005	-1.12	Mid-Range	2005	0.42	Mid-Range
2006	-0.04	Mid-Range	2006	-0.03	Mid-Range
2007	-0.92	Mid-Range	2007	-2.57	Moderate Drought
2008	-0.11	Mid-Range	2008	-1.67	Mid-Range
2009	0.21	Mid-Range	2009	0.14	Mid-Range
2010	1.39	Mid-Range	2010	1.03	Mid-Range
2011	2.93	Moderately Moist	2011	1.72	Mid-Range
2012	-2.21	Moderate Drought	2012	-0.36	Mid-Range
2013	0.27	Mid-Range	2013	-1.89	Mid-Range
2014	1.28	Mid-Range	2014	-2.11	Moderate Drought
2015	-1.25	Mid-Range	2015	-2.38	Moderate Drought

- Stock types are defined based on the latest information posted on the Coeur d'Alene Nursery website (http://fsweb.ipnf.r1.fs.fed.us/nurs/NMIS/user-docs/StocktypeDescriptions.pdf) as summarized in the following table. Stock types that were coded differently were either updated to match the correct type, if it was clear; or, if ambiguous (such as "C"), the code was left as-is.

Table 3: Tree Stock Types, Coeur d'Alene Nursery 2016

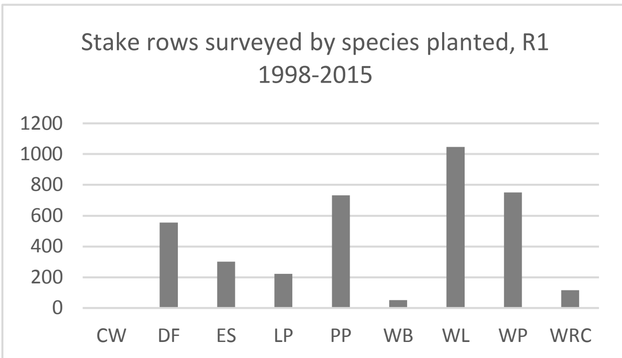
Category	Age/ Size
Bareroot (BR)	**1-0**
Bareroot (BR)	**2-0**
Bareroot (BR)	**3-0**
Bareroot/Container Hybrid	**Plug-1**
Container (CS)	**160**
Container (CS)	**112**
Container (CS)	**91**
Container (CS)	**112L**
Container (CS)	**98**

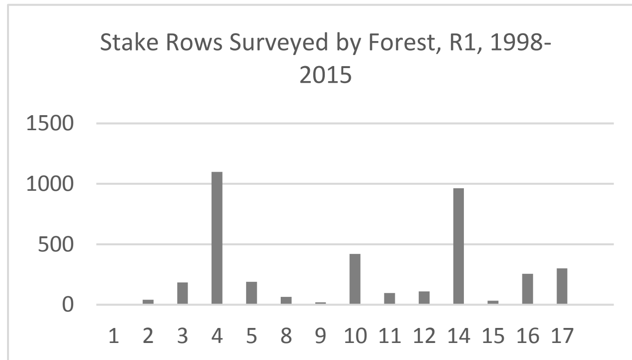
- After the Master data sheet was complete, analysis was done using pivot tables. The data and analysis can be found in *R1Master_StateRow_Data_1998to2015_final.xlsx*.

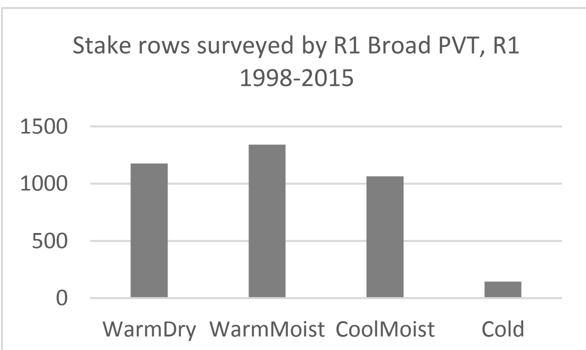
Appendix B: Supplemental Data Charts

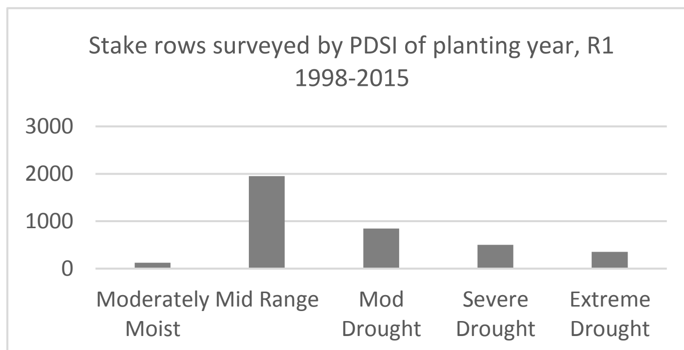
All charts represent the analysis period of 1998 to 2015, unless otherwise noted, and include data from all forests in Region 1 unless otherwise noted. For charts that include R1 Broad PVT or habitat type groups, stake rows with blank habitat types are excluded. For species-specific charts, cottonwood is excluded because it is only represented by one stake row.

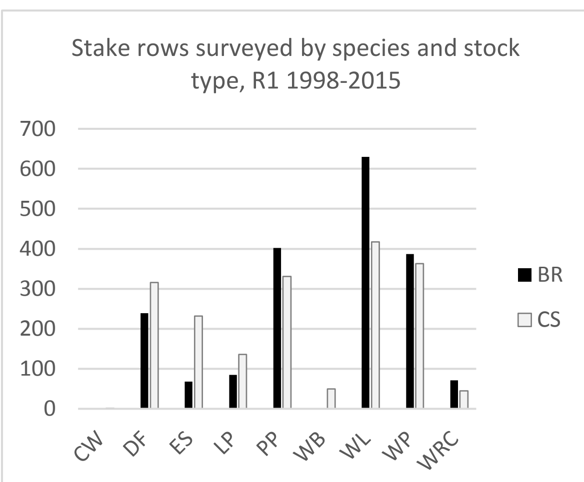
Data Summary

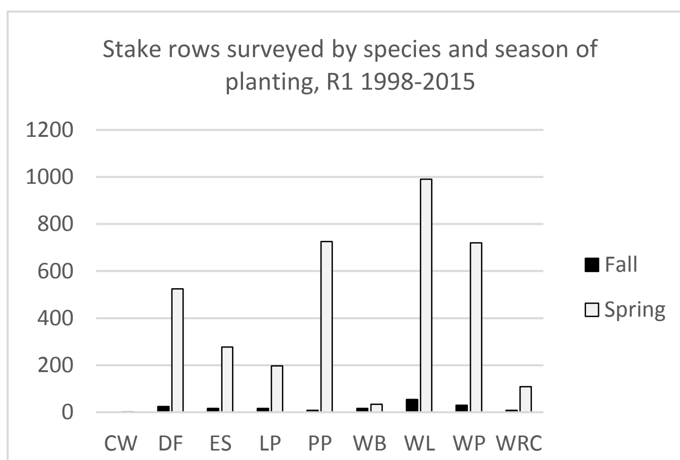


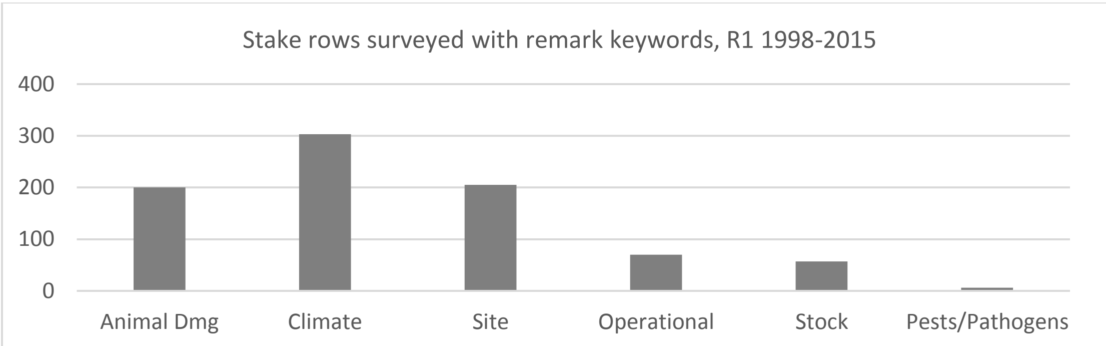




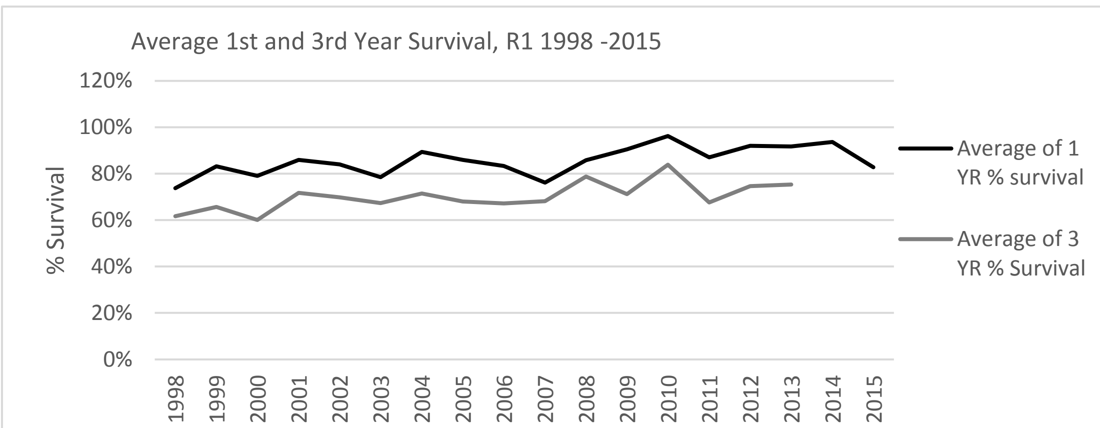


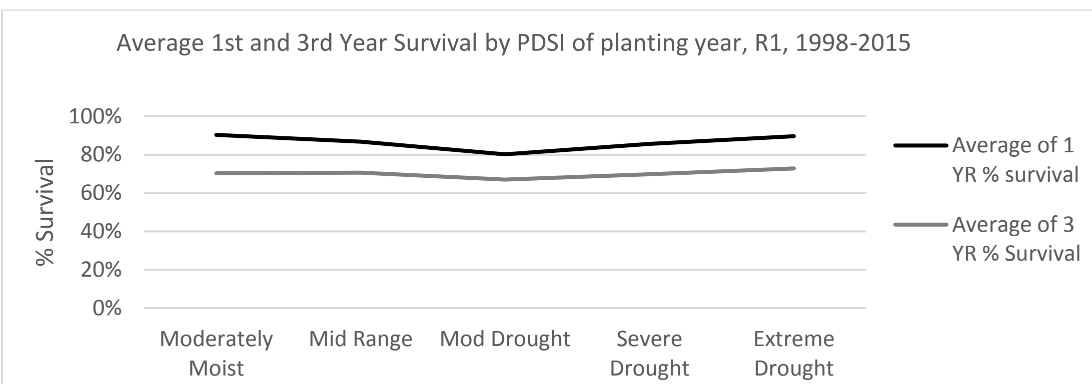


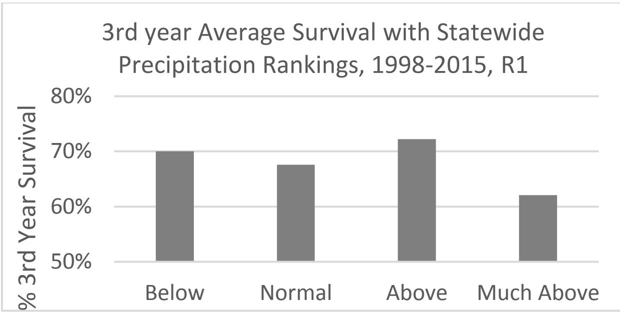


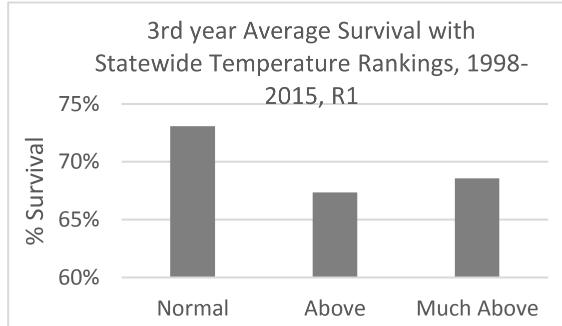


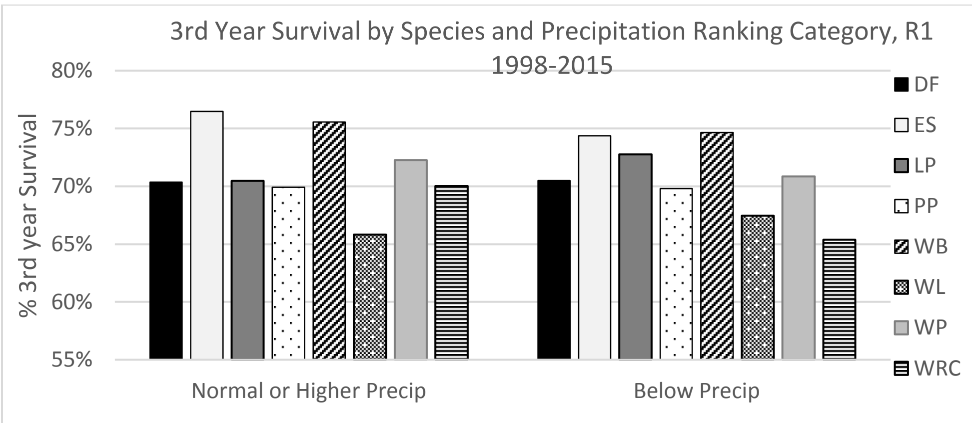
General Climate Influences on Seedling Survival

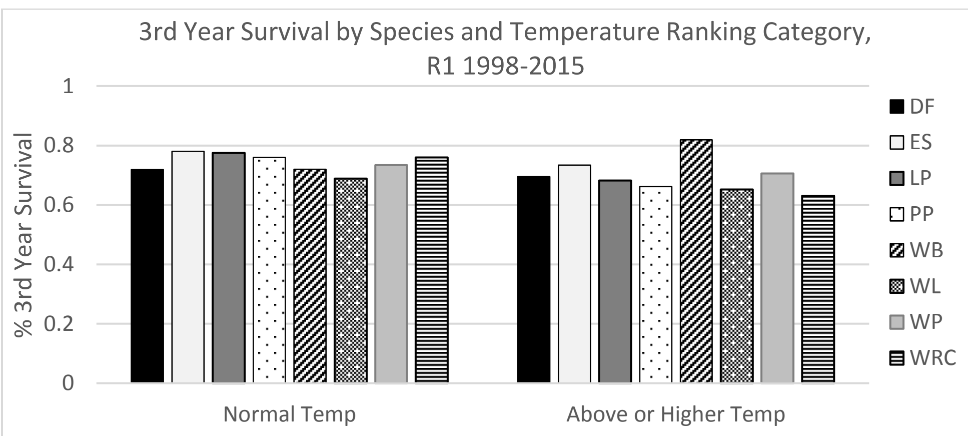


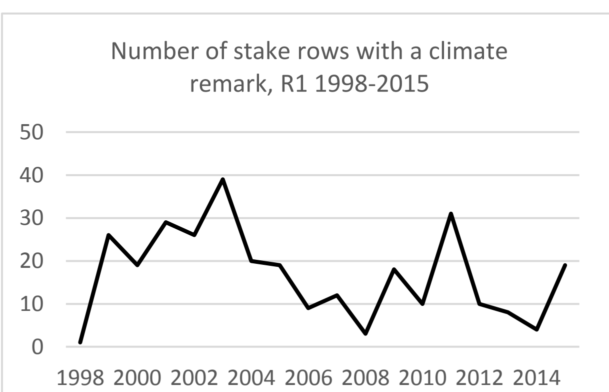


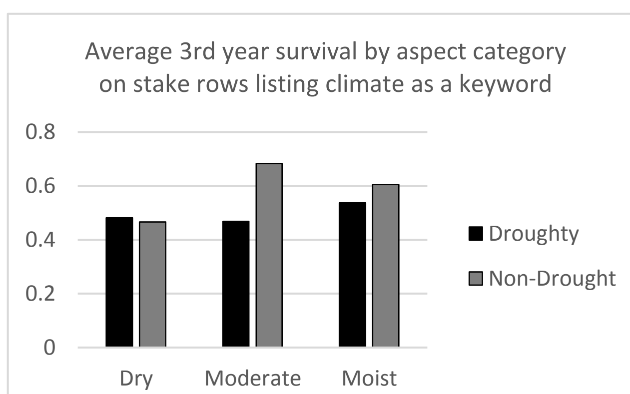

3rd year Average Survival with Statewide Precipitation Rankings, 1998-2015, R1
% 3rd Year Survival
80%
70%
60%
50%
Below
Normal
Above
Much Above

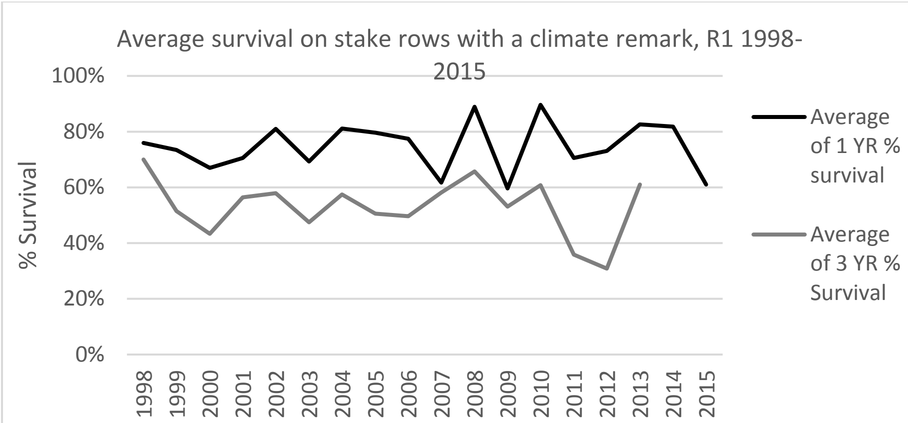

3rd year Average Survival with Statewide Temperature Rankings, 1998-2015, R1
% Survival
75%
70%
65%
60%
Normal
Above
Much Above

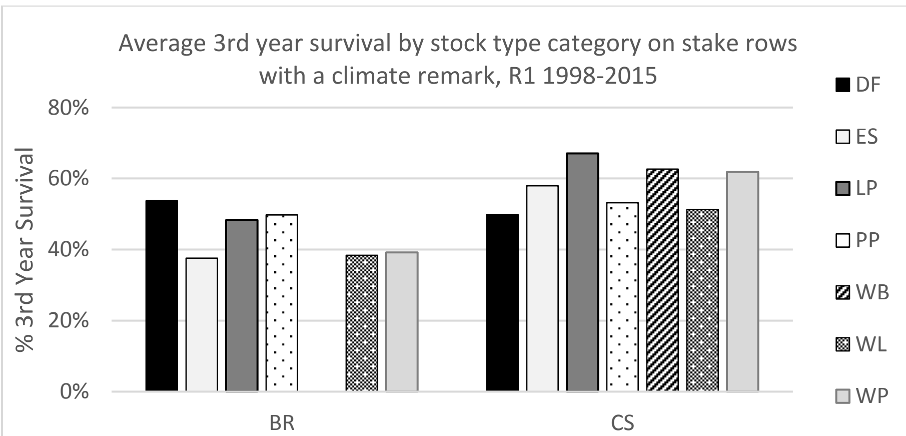

3rd Year Survival by Species and Precipitation Ranking Category, R1 1998-2015
% 3rd year Survival
80%
75%
70%
65%
60%
55%
Normal or Higher Precip
Below Precip
DF
ES
LP
PP
WB
WL
WP
WRC


3rd Year Survival by Species and Temperature Ranking Category, R1 1998-2015
% 3rd Year Survival
1
0.8
0.6
0.4
0.2
0
Normal Temp
Above or Higher Temp
DF
ES
LP
PP
WB
WL
WP
WRC

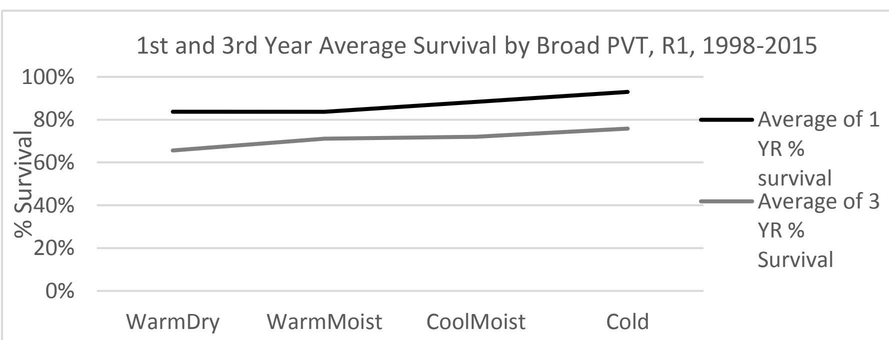

Number of stake rows with a climate remark, R1 1998-2015
50
40
30
20
10
0
1998 2000 2002 2004 2006 2008 2010 2012 2014

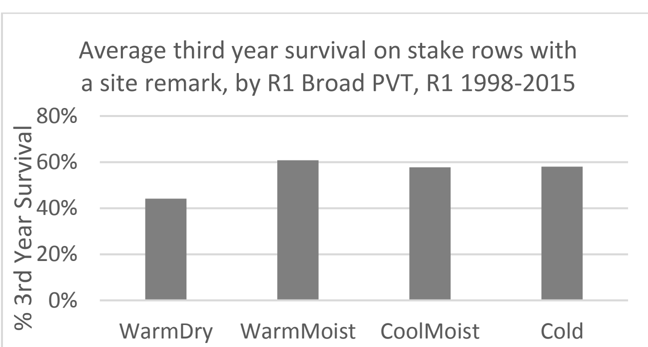

Average 3rd year survival by aspect category on stake rows listing climate as a keyword
0.8
0.6
0.4
0.2
0
Dry
Moderate
Moist
Droughty
Non-Drought

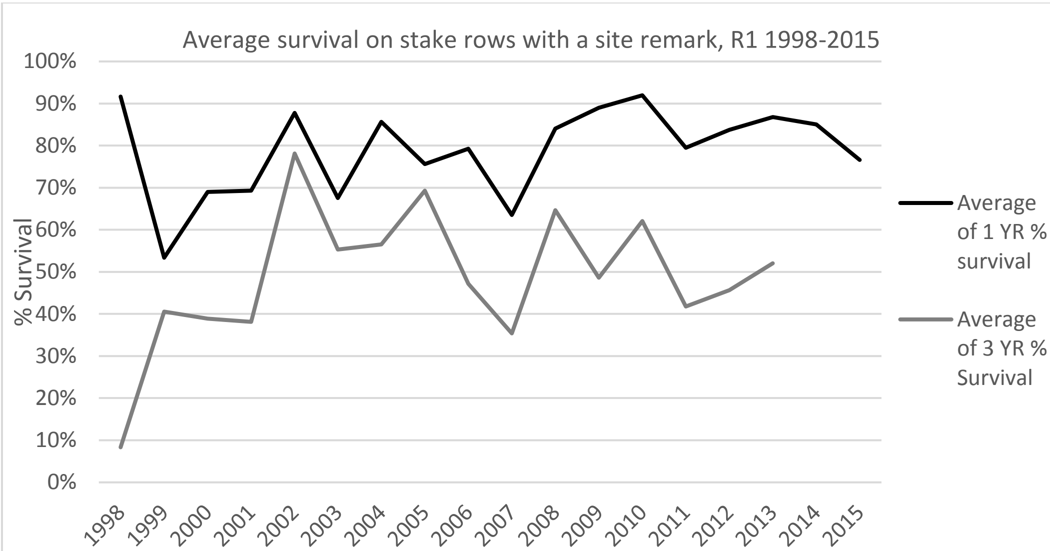


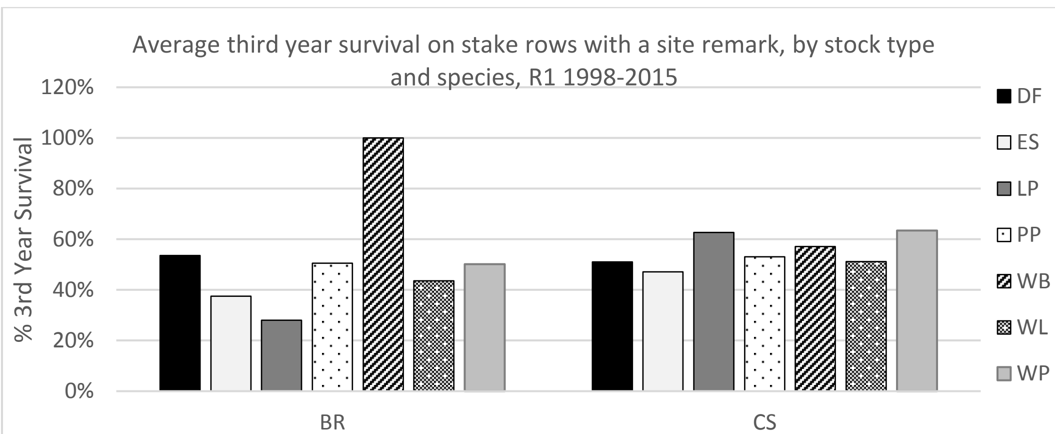


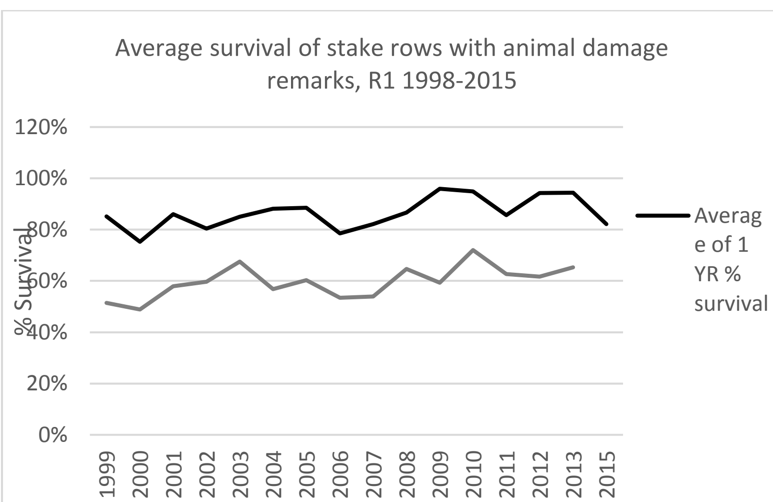
Influences of Site Conditions on Seedling Survival

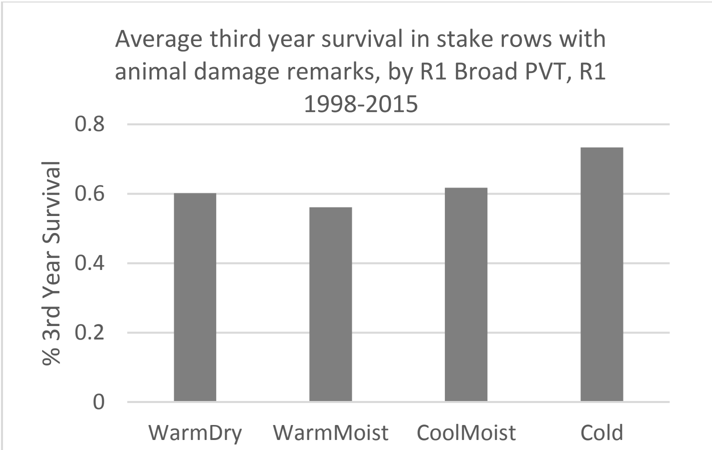




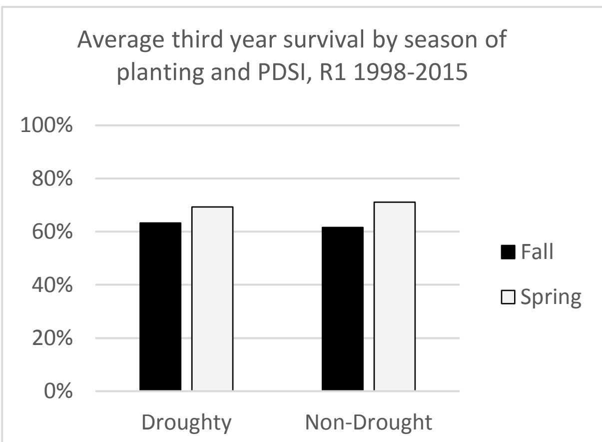

Average survival on stake rows with a site remark, R1 1998-2015
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Survival
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Average of 1 YR % survival
Average of 3 YR % Survival

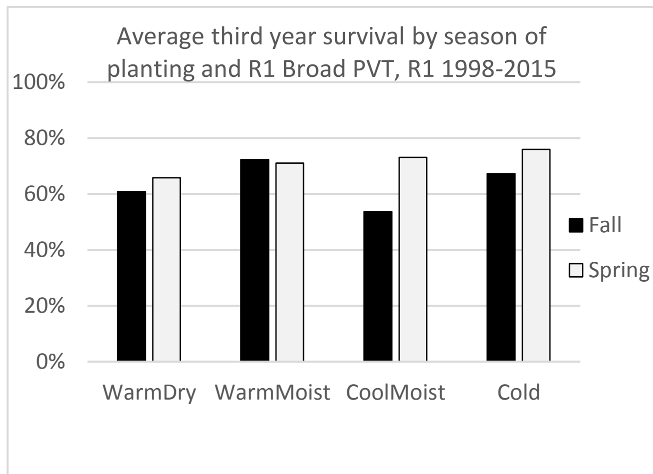

Average third year survival on stake rows with a site remark, by stock type and species, R1 1998-2015
120%
100%
80%
60%
40%
20%
0%
% 3rd Year Survival
BR
CS
DF
ES
LP
PP
WB
WL
WP

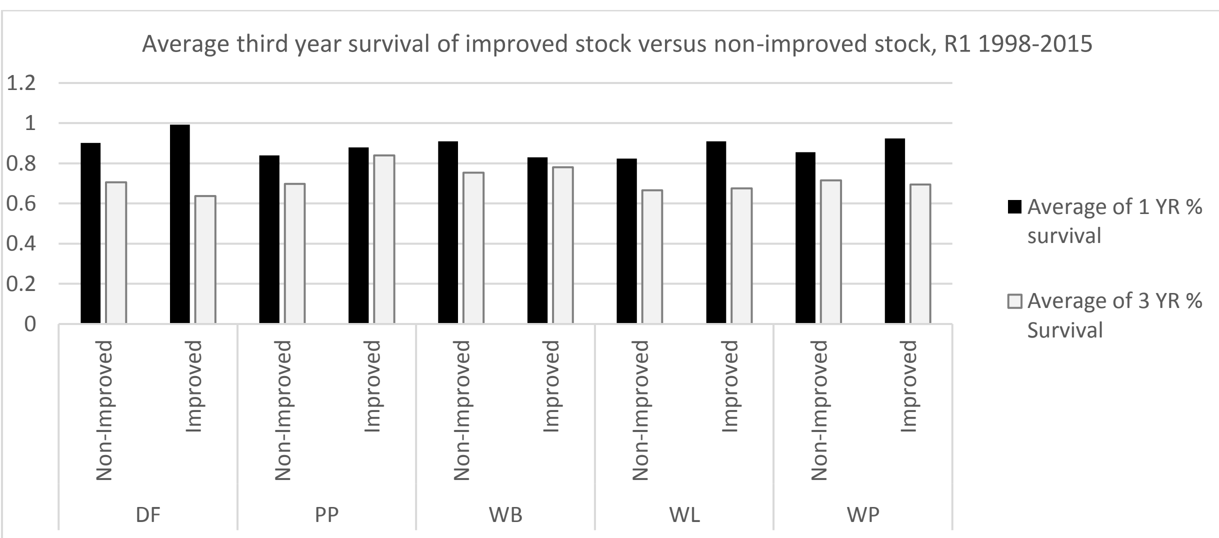

Average survival of stake rows with animal damage remarks, R1 1998-2015
120%
100%
80%
60%
40%
20%
0%
% Survival
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2015
Averag
e of 1
YR %
survival

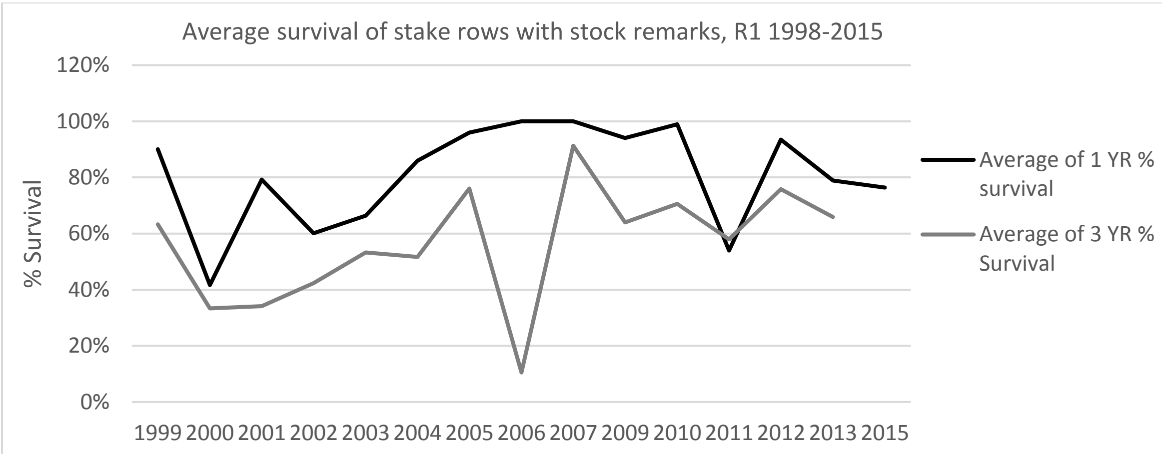


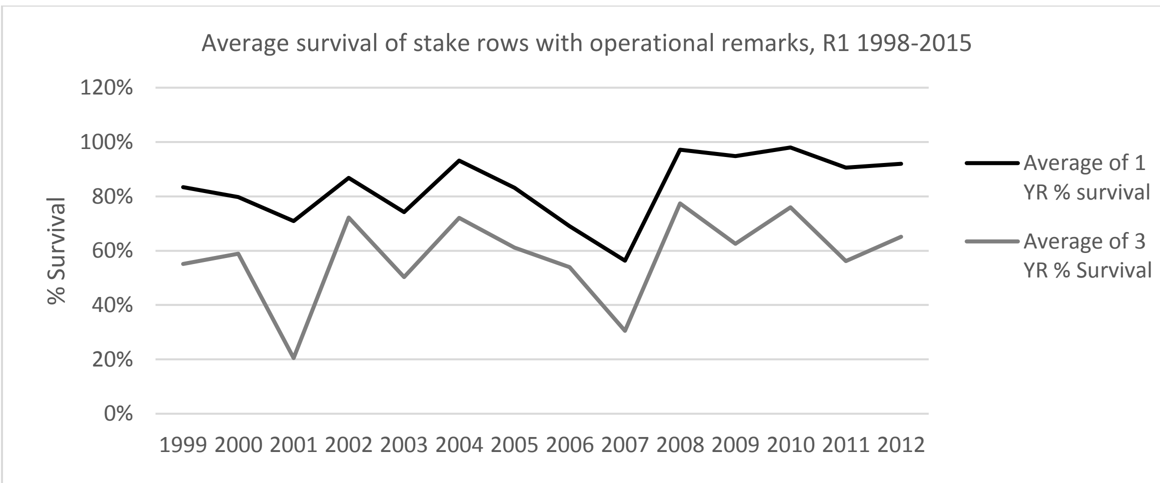
Influences of Implementation Factors on Seedling Survival

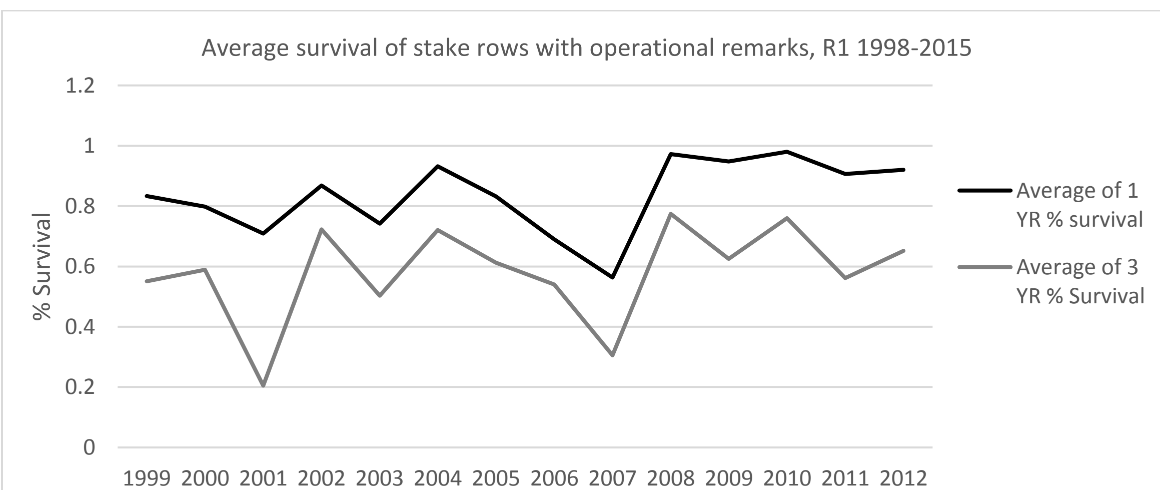




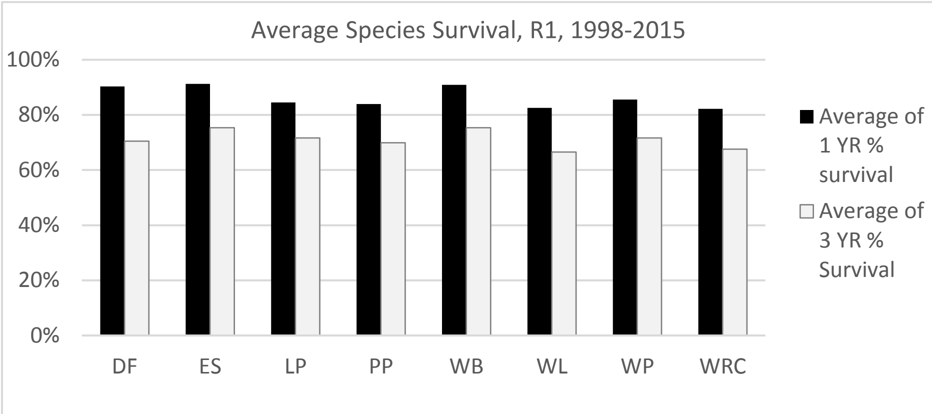


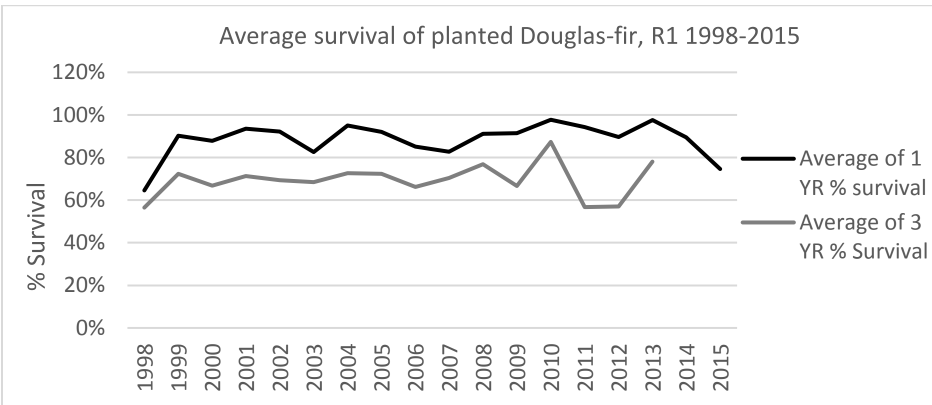

Average survival of stake rows with stock remarks, R1 1998-2015
% Survival
120%
100%
80%
60%
40%
20%
0%
1999 2000 2001 2002 2003 2004 2005 2006 2007 2009 2010 2011 2012 2013 2015
Average of 1 YR % survival
Average of 3 YR % Survival

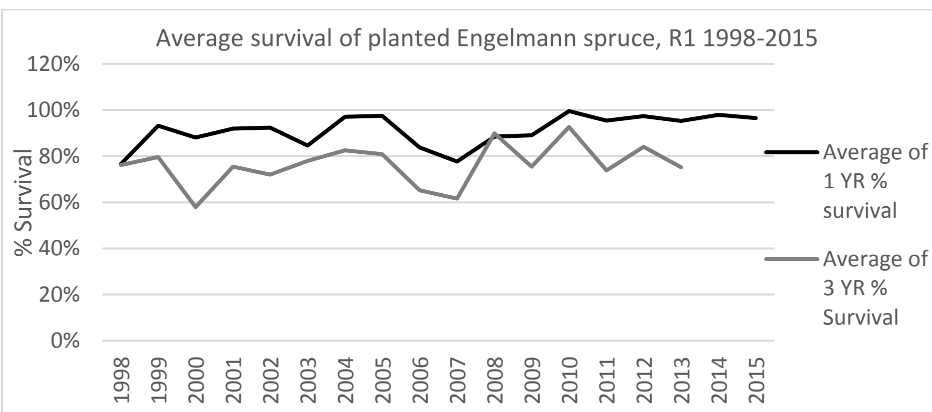

Average survival of stake rows with operational remarks, R1 1998-2015
% Survival
120%
100%
80%
60%
40%
20%
0%
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Average of 1 YR % survival
Average of 3 YR % Survival

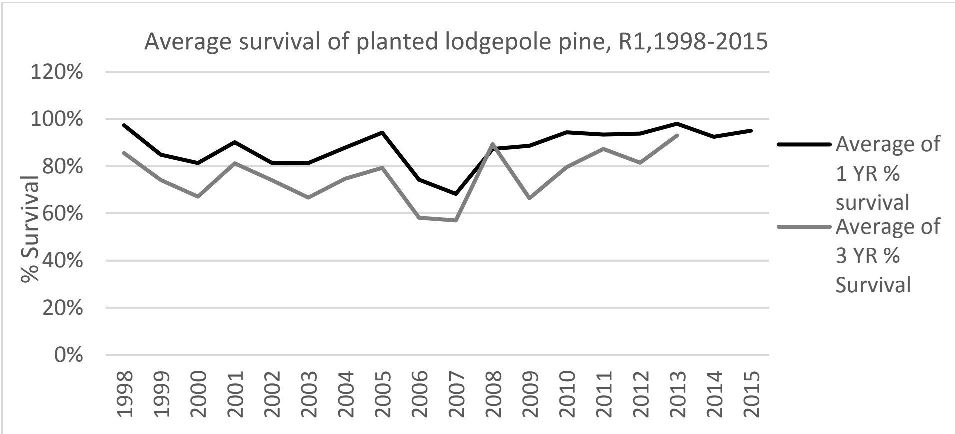

Average survival of stake rows with operational remarks, R1 1998-2015
% Survival
1.2
1
0.8
0.6
0.4
0.2
0
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Average of 1 YR % survival
Average of 3 YR % Survival

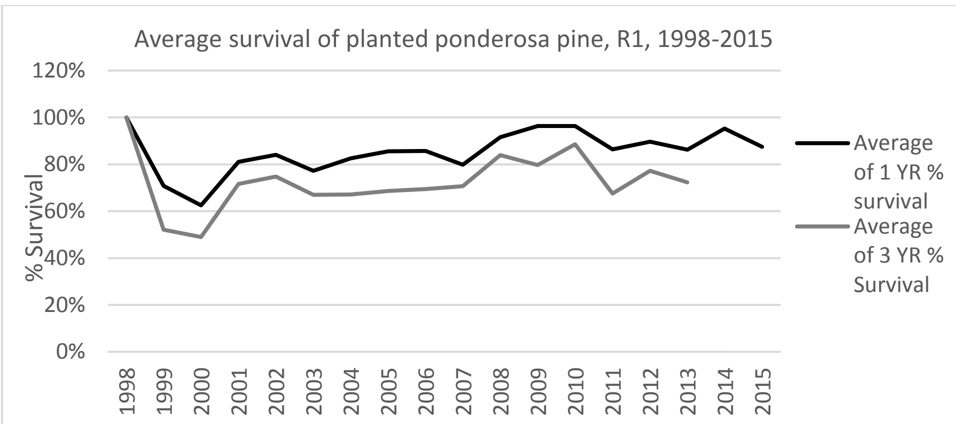
Species-Specific Results

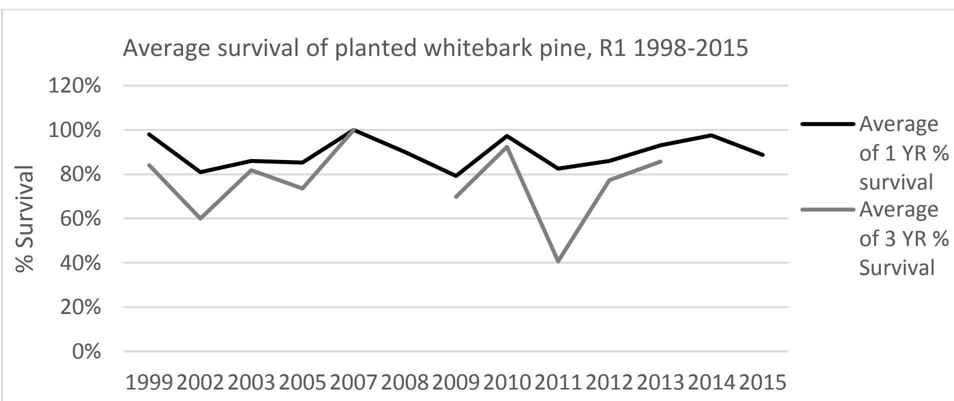


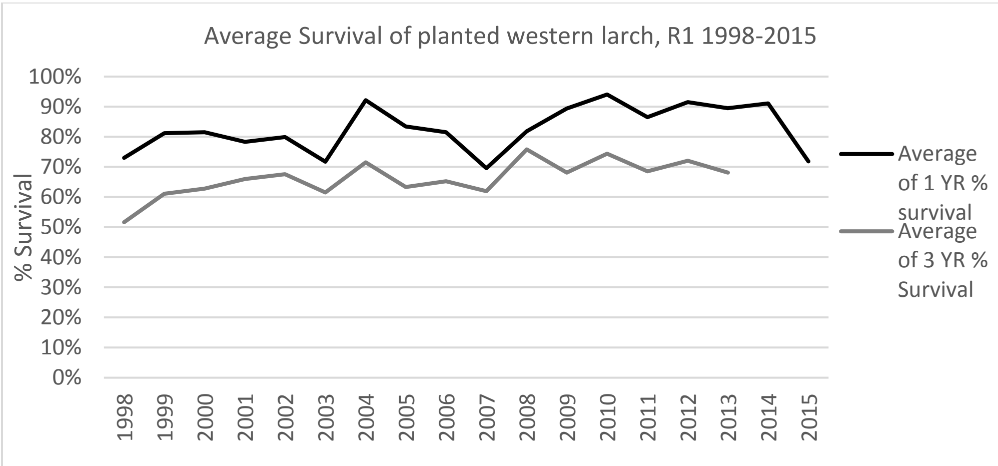


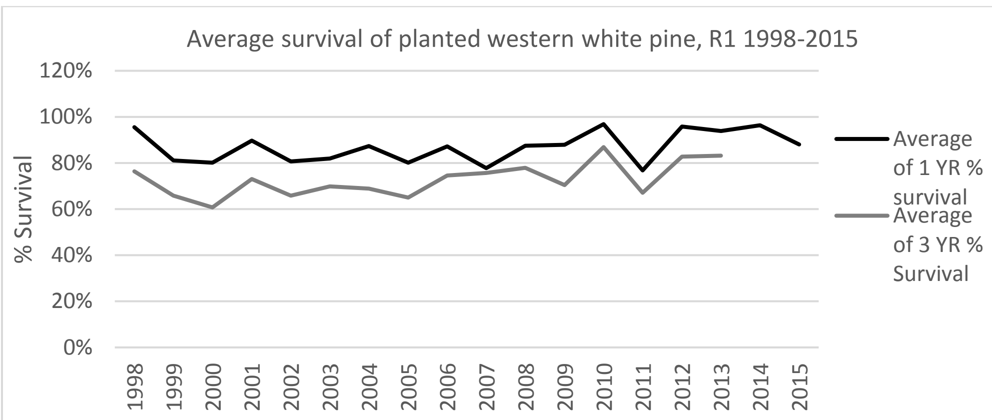


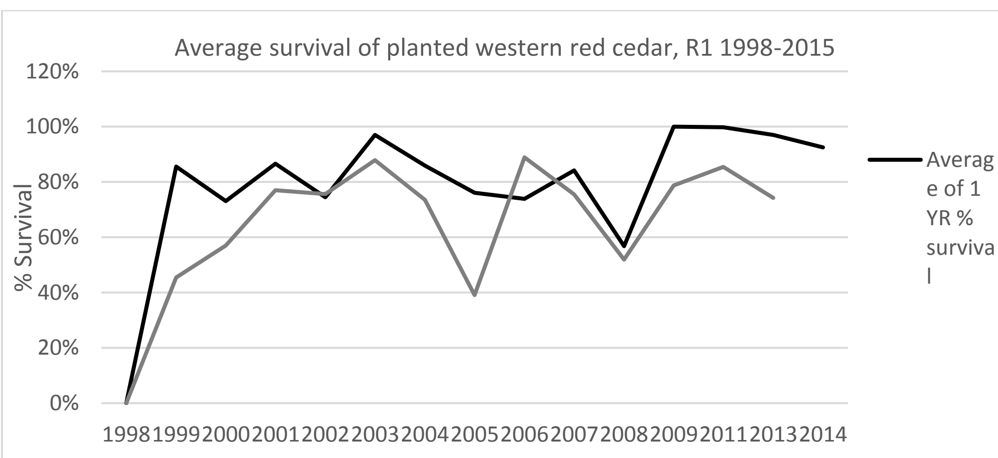

Average survival of planted lodgepole pine, R1,1998-2015
120%
100%
80%
60%
40%
20%
0%
% Survival
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Average of 1 YR % survival
Average of 3 YR % Survival


Average survival of planted ponderosa pine, R1, 1998-2015
120%
100%
80%
60%
40%
20%
0%
% Survival
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Average of 1 YR % survival
Average of 3 YR % Survival


Average survival of planted whitebark pine, R1 1998-2015
120%
100%
80%
60%
40%
20%
0%
% Survival
1999 2002 2003 2005 2007 2008 2009 2010 2011 2012 2013 2014 2015
Average of 1 YR % survival
Average of 3 YR % Survival


Average Survival of planted western larch, R1 1998-2015
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Survival
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Average of 1 YR % survival
Average of 3 YR % Survival


Average survival of planted western white pine, R1 1998-2015
120%
100%
80%
60%
40%
20%
0%
% Survival
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Average of 1 YR % survival
Average of 3 YR % Survival


Average survival of planted western red cedar, R1 1998-2015
120%
100%
80%
60%
40%
20%
0%
% Survival
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2011 2013 2014
Average of 1 YR % survival